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COAL, MINE-GASES, AND VENTILATION

COAL, MINE-GASES, AND VENTILATION

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A TREATISE ON

COAL, MINE-GASES, AND VENTILATION

WITH COPIES OF

RESEARCHES 'ON THE GASES ENCLOSED IN COAL' &c.

BY

J. W. THOMAS, F.C.S.

FELLOW OF THE INSTITUTE OF CHEMISTRY OF GREAT BRITAIN AND IRELAND,
ETC.

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PREFACE.

Owing to the numerous applications which have been received from Mining Engineers, and other gentlemen connected with Mining, respecting copies of the *researches* of the Author '*On the Gases enclosed in Various Coals*,' it was determined to print them collectively, together with other matter closely allied to and connected with the subject.

The 'Papers' having special reference to the gases in coal, and, as a natural consequence, the gases met with in coal mines, it was thought that matter embracing the description and explanation of those gases, and the laws to which they are subservient, might be an addition which would be justifiable, even in the presence of so many valuable works on Mining.

It is hoped that these pages may be of some service to the Overman, Fireman, and other sub-officers of collieries, as there cannot be any knowledge more needful, or more useful, in the general line of colliery management, than that of the gases met with in coal-mines, and the physical laws which govern them.

In carrying out the researches 'On the Gases enclosed in Coal,' the Author endeavoured to elucidate and throw some light upon the processes which had been at work in the formation of coal, and the general extension of the subject. The symbolic notation and technical terms used in the original 'Papers' communicated to the Chemical Society, London, have been replaced by their respective names and terms, in order that they may be more readable by those unacquainted with chemical science.

The chapters on 'Ventilation' are written as elementary as possible; and if the matter in this 'Treatise,' other than the 'Papers' referred to, will meet the end of affording a stepping-stone to the mastering of more advanced works, it will have answered the purpose which actuated the Author in writing it.

THE LABORATORY,
CARDIFF.

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Errata.

Page 5, line 20, *for* inorganic *read* organic.
" 6, line 3 from bottom, and p. 48, line 12, *for* Bishof *read* Bischof.
" 51, line 3, *for* does *read* do.
" 91, *for* Co_2 *insert* CO_2.
" 136, line 6 from bottom, *for* Phillipart *read* Philippart.
" 213, line 23, *omit first* and.
" 281, *for* 40° F., 70° F. *read* 42° F., 72° F., and where repeated to be the same as on table p. 282.

A TREATISE

ON

COAL, MINE-GASES, AND VENTILATION.

CHAPTER I.

COAL.

THIS TERM is at present used in a very wide sense, and, generally speaking, all vegetable matter which has been changed under the influence of ages of time, and which is capable of undergoing combustion in contact with oxygen, is included under the classification of coal. That it is difficult to draw a line of demarcation between those carbon minerals, such as the diamond, graphite, &c., and true coal, will be admitted by all, and that the term is too widely applied will be allowed by most authorities. The word 'coal,' in its general meaning, must include many varieties which will differ considerably; not materially, so far as the elements of which coal is composed are concerned, but greatly in reference to the relative quantities of the constituent elements, and especially in relation to the physical states which prevail.

Organically considered, that is to say, so far as the combustible elements of coal are concerned, carbon is the principal constituent; next comes hydrogen and oxygen, nitrogen and sulphur being present as adventitious bodies. The classification of oxygen with the combustible elements may be objected to, but on reflection it will be seen that it can be regarded as an important supporter of the combustion of hydrogen and carbon.

In a mineral point of view, coal may and does contain more or less of the ash of wood and plants from which it has been produced, in addition to other inorganic matter of a silicious or aluminous nature, which had become mixed with the organic constituents in the processes of change necessary to the formation of a bed of coal. Of other mineral matters, iron, generally present in the coal in the state of sulphide or in combination with sulphur, almost invariably forms a very appreciable percentage. The author regards the iron compounds as being derived from oxide of iron dissolved out of preexisting rocks, and held in solution by excess of carbonic acid in the water in which the wood underwent its chemical changes, or which percolated down to the coal beds after they had become buried under rocky material, and before sufficient covering had accumulated to prevent air and water gaining access to the coaly matter. It would be rational to assume that those beds or seams of coal which appear, from facts gathered in relation to them, to have been formed on the spot where they now lie, contain less ash than those which may have been drifted to a distance, or have occupied and partially filled up what was once a lake. Carefully weighing the evidence of the facts elicited by chemical investigation, it becomes evident that this is the case. When further researches advance us to more correct conclusions respecting the processes which have been at work in the formation of coal, and when we understand more thoroughly the various chemical changes which have taken place, the differences observable in the conditions of various seams in a colliery or in a district will probably be explained in a more satisfactory manner than is possible at present. Coal, then, is fossil fuel—fuel produced and stored up in bygone ages, which by chemical and physical agencies, with and without the presence of heat and moisture, has been modified or resolved into the various forms which bear this name. How many varieties are there, however, which are all included under the head of coal, and which are not available through their rarity or otherwise for fuel purposes? Mineral resin, amber, graphite, and many other substances associated with true coal are embraced under the general term of carbon minerals. The line must be drawn somewhere, or every substance, inorganic or organic, containing carbon, must be included. Therefore any material which, either from its rarity or inadaptability, is unfit for fuel purposes should not be called coal! If all the material which has been derived from the vegetable life which flourished during the carboniferous and miocene periods, and which contain carbonaceous compounds, is to be included under the head of coal, the term is not used in a sufficiently wide sense, as it should embrace the millions of tons of shale, slag, marly matters containing bitumen, oily shales of the rhœtic beds, bituminous nodules, and oily shales of the lias formation, and paraffin oil ought to be called coal also. No man would go to a timber merchant and ask for timber, expecting to be supplied with resin; and mineral resin should not be called coal simply because it has withstood the hand of time and decay, and is now found associated with the remains of the plants and trees which furnished it. Acknowledging their origin, all substances which are of a sufficiently definite character to receive a distinct name are usually regarded as a class, and the term 'coal' should not include—and indeed is seldom used as including—any substance, however combustible, which is not directly available for fuel purposes, and capable of being burnt in an ordinary furnace or fire-grate.

Although there are few who have any doubt respecting the origin of coal, so far as the material from which it has been derived being of a vegetable character, there are many doubts concerning its mode of formation, and the manner in which beds of coal have been produced. The generally accepted hypothesis is, that the greater portion of the coal beds of the carboniferous period occupy the position on which the forests or other vegetable growths originally grew and flourished. There are many more rational proofs in favour of this view than can be adduced to uphold the hypothesis of beds of coal being formed by the accumulation of organic matters in the bottom of an ancient ocean or of deep lakes. That some of the coal beds have been formed in the latter way, and that others of small area are constituted of the organic material drifted into lakes, admits of little doubt; but, in the absence of absolute proof, it is more in harmony with common sense to admit that the land, with its vegetable life and plant material, became submerged at intervals, and that the beds of coal rest on the soil in which the original trees and plants grew. There is, moreover, much proof in favour of the *in situ* theory, as instances of every-day occurrence are known of the roots of trees being found, firmly imbedded in the bottom clay, which is supposed, with some degree of reason too, to be the soil which supported the plant life. Even in our day variations in the earth's surface occur—land is submerged, and submerged land is raised. No one doubts that trees and other living organic growths became buried under clayey and other inorganic matter which now forms rocky material, and that the vegetable matter has by some process been converted into coal. A very interesting consideration respecting this subject is, how this inorganic matter became converted into coal. That this is a question, the satisfactory answering of which is surrounded with almost insurmountable difficulties, there is little doubt; and if all the respective hypotheses were discussed, and their relative values determined, it would require such space that volumes would result in consequence. The terrestrial agencies which have assisted in the conversion of vegetable material into coal are, principally, moisture and heat.

It is intended to confine the remarks upon the formation of coal given in this volume, as far as possible, within the limits of the results which have been obtained in the author's investigation of the 'gases enclosed in coal,' the papers on which (as communicated to the Chemical Society of London) are given in detail in the Appendix. It is thought that a determination of the gases which are held imprisoned in the pores or interstices of the coal, will throw much light upon the nature of the alteration, dissociation, or decomposition, which has taken place.

Taking the mean of the many analyses of coal made by various chemists, the following table will illustrate their composition, as also wood and peat (calculated on the dry sample):—

Substance	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
Wood . . .	50·0	6·0	41·5	1·0	—	1·5
Peat . . .	58·0	5·5	29·0	1·5	—	6·0
Anthracite . .	91·5	3·0	1·5	1·0	1·0	2·0
Steam Coal . .	89·0	4·0	2·5	1·0	1·0	2·5
Bituminous[1] Coal .	81·0	5·0	8·0	1·5	1·0	3·5
Cannel Coal .	80·0	6·0	7·0	1·5	1·0	4·5
Lignite . .	56·0	5·0	25·0	1·5	2·0	10·5

Sulphur and ash are included in the table, because, as will be shown anon, some importance is attached to them. The composition of wood and peat is given for comparison. On comparing the constituents of wood with those of coal and peat, it will be noticed that in no instance does the hydrogen or oxygen in the latter amount to so large a percentage as that present in the former (wood). Liebig and Bishof have shown that in the form [illegible] following reactions may have [illegible] may have combined with oxygen to form carbonic acid, or with hydrogen to form marsh-gas, and that hydrogen may have combined with oxygen to form water. From the researches of the author, it appears that carbon has, to a certain extent, combined with different proportions of hydrogen, as shown in hydride of ethyl (C_2H_6), marsh-gas being CH_4.

---

[1] House coals, cann [illegible] character.

Wood and substances allied to it are generally regarded as the primary compounds from which all coal has been produced, and it has often been asserted, if indeed it be not a widely received hypothesis, that the ultimate termination of the processes of the conversion of vegetable matter into coal is to be seen in *anthracite.* Taking wood as the starting-point, and anthracite as the ultimatum, it is possible to select the analyses of a number of coals, which, when arranged in a table, will show a somewhat gradual change from the former to the latter. If sufficient evidence did exist to prove that only one distinct chemical process had been at work in the formation of coal, then it would be only rational to assume that all highly hydrogenised coals would, after an indefinite period, be transformed into anthracite; but there is much evidence against the acceptance of this hypothesis, some of which will be referred to in future pages.

Vegetable, and organic matter generally, in the act of undergoing decomposition, either on the surface or immersed in water, evolve carbonic acid and marsh-gas; but the quantity of the latter gas is not so great, probably, as is generally imagined. It is extremely difficult to arrive at a correct result in reference to the ratio which the marsh-gas generated bears to the carbonic acid, owing to the latter being readily soluble in water, and hence the nature of the reactions which vegetable matter undergoes when immersed in water cannot well be determined. The compounds in vegetable matter which most readily undergo decomposition when vitality has been destroyed are some of the carbon compounds containing hydrogen and nitrogen, and the production of marsh-gas is, in great measure, due to the decomposition of the same. This remark is applied in reference to the production of marsh-gas (fire-damp) in the instances in which it is the result of the primary decomposition of organic matter at or near the earth's surface, and in the presence of moisture. In pools of stagnant water which receive accumulations of leaves, and in which active decomposition is going on, marsh-gas is formed in considerable quantity, but as soon as the softer portions of the leaves are decomposed, and active chemical change has been retarded, the production of marsh-gas is relatively much lessened; and in ponds of stagnant water which contain woody matter, the generation of that gas is scarcely recognisable. When woody matter is congregated at the bottom of deep ponds, and the supply of oxygen is, in consequence, more limited, the quantity of marsh-gas generated is very little, and I have been unable to cause any bubbles of gas to rise from decomposing organic matter situated at any considerable depth. Marsh-gas is but very sparingly soluble in water, but, it is true, a little may become dissolved. The decomposition of the more readily oxidisable constituents of the plants from which coal is formed would, no doubt, be accelerated by the somewhat tropical climate and high temperature which appear to have prevailed during the coal period. It is probable that, as soon as the organic material became buried under an appreciable thickness of inorganic matter, the chemical reactions which took place, as ages rolled on, were such as bore little or no relation to that which took place when the vegetable matter, recently vital, underwent decomposition at or near the earth's surface. It is very probable, too, that a great portion of the organic material from which coal is formed became submerged in such a manner as to be practically removed from the influence of either air or oxygen, and that too with considerable rapidity. Under these circumstances, much of the more readily oxidisable compounds were dissolved in the water, and the nature of the decomposition which resulted would doubtless be influenced in no small degree thereby, especially if the temperature remained low. The production of marsh-gas would appear to be very effectually lessened, if indeed not entirely prevented. The reason for this conclusion will become more evident when the enclosed gases in lignite are under consideration. Leaving that portion of the subject referring to the first or primary decomposition, it will be best to consider that the coal material has become buried at some depth below the earth's surface. As long as it remained in a wet condition, uninfluenced by temperature above the normal point, it is not at all likely that changes would take place and be continued which would have the effect of ultimately forming anthracite. The superior combining affinity of carbon for oxygen over that of hydrogen, as shown in the destructive distillation of coal durin the manufacture of coal-gas, and that too whe carbon is combined with hydrogen in the form marsh-gas, hydride of ethyl, &c., as proved by th experiments of Dr. Von Meyer and the author, tenc to indicate that the combined oxygen of wood material would be used up by the carbon leaving great portion of the hydrogen intact. In this mann the percentage of carbon in ratio to hydrogen woul not be much increased, and the product formed aft slow decomposition through numberless ages migl be of a bituminous character. When new beds vegetable matter were formed, and the older an lower ones were buried deeper and deeper under tl earth's surface, the latter would, as ages rolled o be more and more removed from the influence water and dissolved oxygen, and when the sean were so buried as to be out of the reach of air an water, the oxidation which ensued would take pla at the expense of the combined oxygen of the wood material. Those beds of organic matter which we desiccated in the earlier period of their formatio and which may have remained in that condition unt now, constitute, we think, the anthracitic seams veins which occupy the lower portions of the co measures in many parts of the carboniferous form tion in Great Britain. The steam coals of the Sout Wales basin are among this class, and all tho coals which occlude much marsh-gas are capable being thus classified. The foregoing consideratio refer to the decomposition or resolution of organ matter into coal under the ordinary conditions temperature, and of the long-continued and slow conversion of organic matter into coal, through countless ages.

In those instances in which heat was brought to bear upon the coal-seams during the process of formation, with or without the presence of moisture, the nature of the reaction which took place would naturally vary according to circumstances. During the formation of true anthracite, and the more highly bituminised varieties of coal, cannel and jet for instance, the effect of an elevated temperature, combined with excessive pressure, would hasten the conversion of the organic material into coal, and probably render the product more stable; and the absence of one or both of these forces would have the effect of varying the nature of the decomposition or oxidation which took place. Judging from the stable character, condition, and composition of the coals of the carboniferous formation, it does not appear at all likely that the more bituminous varieties would be, after the lapse of any length of time, transformed into anthracite. Ornaments made of jet and varieties of cannel resist atmospheric influences to all appearances equally as well as anthracite.

In wood, the percentages of hydrogen and oxygen are present in very nearly the proportion required to form water, and, as will be seen from the table, some of the coals contain their hydrogen and oxygen arranged in a somewhat similar condition. The hydrogen in coal is, however, always in excess over that required to form water with the oxygen, and this excess has been styled 'disposable hydrogen' by some chemists, who regard the non-disposable hydrogen as being actually in combination with oxygen (as water of combination) in coal. Water is composed of two atoms of hydrogen and one atom of oxygen, H_2O, and oxygen being sixteen times heavier than hydrogen (hydrogen being 1), it follows, that it will take nine times as much oxygen by weight as of hydrogen by weight to form water. The fact must not be lost sight of, however, that the composition of seasoned wood bears very little relation to that from which coal is produced. The lower strata of vegetable matter, forming a layer above the soil of the forest, must have undergone a very considerable change before the latter was submerged: the more volatile and more easily oxidisable portion having been resolved, and partly converted, into gaseous compounds. Again, there must have been a fair proportion of dried trunks of trees, and wood in a rotten condition, like to that found in our own forests of the present day. These, therefore, taken together with the vegetable life of the period, would give an average composition widely different from that of seasoned or air-dried wood, and would bear little or no resemblance to it. After this material was buried, there is no telling for what period some of the coal beds may have remained subjected to the action of water and dissolved oxygen, and, on this account, it is superfluous to say, that in case the ultimate character of the beds referred to was anthracitic, that the hydrogen became oxidised, leaving the carbon comparatively intact.

Owing to the admixture of the vegetable matter from which coal is formed with more or less inorganic substance, the correct determination of the ash which has been derived exclusively from the mineral matter of wood is simply impossible, otherwise a chance would be afforded of defining, with almost unerring certainty, the exact nature of the processes which have been at work in the formation of coal. The soluble portion of the mineral constituents of wood may have been, and was probably, removed by prolonged soakage below the surface of the ocean, and the composition of the ash of coal may not be expected, therefore, to bear relation to that of wood. Generally speaking, the higher the percentage of carbon in a sample of coal is, the lower is the percentage of ash which it contains, and the higher the percentage of hydrogen is, the higher is the percentage of ash. There are exceptions, as indeed there are in every branch of the subject, but these are not sufficient to influence the value of the deductions to be drawn from the general evidences. The percentage of ash in most coal is very much greater than that present in dry wood, and calculating from the average of good useful coal, it may be stated as being five times as great. In making this comparison, the ash of the slow-growing, close-grained, hard woods are not taken into account, as we have no evidence that these flourished during the coal period. One curious exception to the ash of coal being greater than that of quick-growing soft wood came under the notice of the author during the analysis of a sample of steam coal from Llwynypia Colliery, Rhondda Valley, in which the percentage of ash was only 0·67—this is as low as the ash in dry pine wood. The fact that the ash in coal is usually much greater than that in wood, shows the possibility of the loss of a considerable proportion of *carbon* (as well as hydrogen and oxygen) which may have united with the combined oxygen to form carbonic acid; and this oxidation of carbon has, possibly, been at work to a greater extent than is generally believed.

The process which has been at work in the formation of anthracite will be first considered from the composition of the gases which were found to be enclosed in this class of coal. The anthracites, which were examined by the author from the western portion of the South Wales coal field, contained an immense volume of occluded gas; one sample yielding no less than 1875 c.c. per 100 grams. of coal, or more than 24 times its volume of gas. When the closeness of the structure of these coals is taken into consideration, it is very surprising how they can hold it, as the gas must be imprisoned under enormous pressure. This fact tends to show that the beds of anthracite must have been, at one period of their history, covered by a great depth of strata since removed. The composition of the gas withdrawn from anthracite in a vacuum at the temperature of boiling water was :—

	1.	2.
Carbonic acid	2·62	14·72
Marsh-gas	93·13	84·18
Nitrogen	4·25	1·10
	100·00	100·00

No. 1 was from Bonvilles Court, Pembrokeshire; No. 2 was Watney's Llanelly, Caermarthenshire.

The anthracites contain a high percentage of marsh-gas, a low percentage of nitrogen, and an appreciable percentage of carbonic acid. In No. 2

the percentage of carbonic acid is considerable, while that of nitrogen is strangely low. It would appear, therefore, that in the process of formation, the oxidation of the carbon to carbonic acid took place chiefly at the expense of the combined oxygen, as the percentage of nitrogen bears no relation to that which should be present, provided it came from atmospheric air. Under these circumstances, the hydrogen combined with carbon to form marsh-gas, the hydro-carbon element of fire-damp. The anthracites are derived, probably, from organic material, which became buried very rapidly under a considerable thickness of inorganic matter, and that, too, with the total exclusion of air and water. The first reaction which took place after being so buried was, possibly, that of the oxidation, by the combined oxygen, of some of the carbon to carbonic acid, and some of the hydrogen to water, followed by the slow oxidation of carbon to carbonic acid, and the combination of hydrogen with carbon to form marsh-gas, the result being anthracite. These changes would be much accelerated by heat and pressure, and the anthracites bear the evidences of such forces by their dense, hard, and close-grained structure. The steam coals, which belong to the anthracite class, have undergone a process, probably, not dissimilar to that of true anthracite, with the exception that heat and pressure have not exerted so great an influence in the change. The evidences of heat upon the South Wales coal field are, more particularly, discernible in the western portion, and they become, apparently, less as the centre of the coal field is reached. Many of the steam coals—in fact, the greater number of them—do not show that they have been exposed to a temperature much above that which we believe existed at the depth they were, at any time, buried beneath the surface. The enclosed gases in steam coal, after removal from the pit, do not bear much ratio to those which were present in the coal previous to the seam being worked, owing to the immense volume which has escaped;—the greater portion being marsh-gas, so that the following figures would nearer represent its average composition:—

Carbonic acid	1·5
Marsh gas	95·0
Nitrogen	3·5
	100·0

The influence of greater heat and pressure would have the effect of hastening the conversion of the organic material into anthracite—the steam coals losing their oxygen and hydrogen less completely. When the hydrogen in the enormous volumes of marsh-gas in steam coal is approximately calculated, it appears to amount to nearly as much as was present in the organic matter from which it was produced,—that is to say, the amount of hydrogen (possibly about 6 per cent.) which would have been present when the coal material became buried under sufficient rocky matter to be beyond the reach of air and water. Thus accounting for the hydrogen, the combined oxygen entered into combination with carbon to form carbonic acid—at least a great portion of the oxygen would be thus used up.

A curious circumstance connected with the coals of the anthracite class is, that when there is a high percentage of carbonic acid present in the enclosed gases, the percentage of nitrogen is usually very low; this anomaly (see pp. 341, 342, Appendix) bears evidence against the theory that the oxygen of the carbonic acid is derived from atmospheric air.

Bituminous coals, other than cannel, usually contain small volumes of enclosed gas, and the two following analyses may be taken as typical of this class, especially so far as the North of England and South Wales coal fields are concerned. No. 1 is No. 3 on Dr. Meyer's table, p. 40, and No. 2 is No. 12 on the table page 339, Appendix.

	No. 1.	No. 2.
Carbonic acid	20·86	9·43
Oxygen	4·83	2·25
Marsh-gas	—	31·98
Nitrogen	74·31	56·34
	100·00	100·00

The greater portion of the oxygen had found its way into the coal by diffusion. When the coals of this class are situated near the surface, they contain enclosed gas similar to No. 1, which is free from marsh-gas, while those coals which are obtained from a considerable depth from the surface contain gas, intermediate in composition with steam coal and the bituminous coals already mentioned,—that is to say, they contain an appreciable percentage of marsh-gas. It does not appear, therefore, that coal material, after becoming buried and compressed, evolved any marsh-gas while in a position in which water or dissolved oxygen could gain access to it, and in the decomposition which has taken place, hydrogen has been converted into water, while much carbon has been oxidised to carbonic acid; and this is not unlikely the reaction still going on, the oxidation of the carbon taking by far the greater lead.

The bituminous coals do not appear to have been subjected to excessive heat, although they show evidences of much pressure; when, however, they are selected in accordance with the percentage of hydrogen which they contain, and the 'fat gas coals' are reached, the evidence of heat becomes more apparent; and these have probably undergone a process of decomposition not unlike the cannel coals, which they most resemble.

Cannel coals, like the true anthracite, are very dense and hard, and appear to have undergone a process of partial fusion, more especially those of Scotland. The Wigan cannels, which, in some instances are associated with beds of more anthracitic coal, are somewhat intermediate with steam coal and Scotch cannel. The following analyses show the composition of the enclosed gases in Wigan cannel No. 1 (No. 1 on p. 355, Appendix) and Scotch cannel No. 2 (No. 4 on p. 357, Appendix).

	No. 1.	No. 2.
Carbonic acid	6·44	84·55
Marsh-gas	80·69	—
Hydride of ethyl	4·75	—
Hydride of propyl	—	0·91
Nitrogen	8·12	14·54
	100·00	100·00

No. 1 contained a large quantity of enclosed gas, No. 2 comparatively a small quantity.

The Wigan cannels, like the steam coals, appear to have been buried and removed from the influence of water and dissolved hydrogen at an early period, and under such conditions that the greater portion of the hydrogen remained. It may be, too, that these coals are composed of vegetable matter originally more rich in hydrogen than that from which ordinary coal is produced. In any case, the process of formation is indicated by the hydrogen combining with carbon, while little, if any, has become oxidised to water. Wigan cannels generally contain a low percentage of ash, which, after deducting the iron corresponding to the amount of sulphur, leaves very little remaining. It may be assumed, therefore, that the carbon of the organic material was not to a great extent oxidised, the carbonic acid being formed, for the most part, at the expense of the combined oxygen.

The Scotch cannels were, it is probable, exposed to the action of water and dissolved oxygen through countless ages, the carbon being gradually oxidised to carbonic acid like that of the lignites of the present day, while a portion of the hydrogen was eliminated in combination with oxygen as water. By the subsequent effects of heat and pressure they became more condensed, some of the hydrogenised compounds being resolved into gaseous and liquid compounds of lesser density, and agreeing in composition with the heavier gases of the marsh-gas series, where each atom of carbon is combined with twice as many atoms of hydrogen, and two more atoms of hydrogen added; thus—CH_4, C_2H_6, C_3H_8, C_4H_{10}, &c. Under these circumstances, the oxidation of carbon to carbonic acid was most energetic, as shown by the large percentage of carbonic acid which the Scotch cannels contain. The ash in these cannels is usually high when compared with the Wigan cannels and steam-coals, and it is probable that a very large proportion of the carbon, originally existing in the coal material from which they are formed, has been oxidised.

Many of the North of England highly bituminous coals (good gas coals), which are very close-grained and dense, may have been, likewise, subjected to the conditions cited respecting the Scotch cannels; the effect of heat being less in some instances.

The lignites belong to much more recent formations than the carboniferous. The Bovey Heathfield lignite is of the Miocene age. The enclosed gases in the lignites of Bovey Heathfield, withdrawn at 50° C. (122° F.) may be represented by the following analysis:—

Carbonic acid	98·30
Carbonic oxide	1·35
Hydrocarbon gases	traces
Nitrogen and traces of oxygen	0·35
	100·000

The above is the composition of the enclosed gas in compact lignite—the more earthy lignites contain more carbonic oxide and nitrogen. This analysis, however, represents the average composition of the gases in the lignites of the Continent, as far as they have been examined by the author. The enclosed gas in lignite is, practically, carbonic acid. The process of decomposition appears to have been constant and alike since the beds were congregated; for, in this instance, it is likely that the seams are constituted of drift wood and vegetable matter in the shape of leaves, &c. The Bovey beds have doubtless been, with little interruption, under the influence of water and dissolved oxygen since they were deposited, and a careful study of this formation would possibly be productive of much good in throwing light upon the formation of coal generally. Much of the carbon of the matter from which lignite is formed has, doubtless, become oxidised to carbonic acid, while more or less of the hydrogen has been converted into water. A very excellent description of the Bovey Tracey lignites, by Mr. Pengelly, will be found in the 'Transactions of the Royal Society,' 1861.

The author regards the process of the formation of coal (after the first or primary decomposition which ensued during the time the vegetable matter was in the act of being buried) to have taken place in four ways, viz. :—

1. The dry process aided by heat, leading to the production of anthracite.
2. The dry process without much abnormal heat, to which the production of steam coal and Wigan cannel is due.
3. The wet process with heat, to which may belong the production of Scotch cannel and the more dense varieties of bituminous or house coals.
4. The wet process without long-continued heat, to which we may assign the formation of ordinary bituminous (house coals) and lignite.

Microscopical Appearances.—True coal does not show much evidence of vegetable origin when examined under the microscope, owing to the change which has taken place during the conversion of the organic material into coal. Some varieties have been subjected to so much compression, aided, probably by heat, that their appearance leads one to suppose that almost complete fusion has taken place. Other varieties, through long-continued dry decomposition, which resulted in the gradual dissociation of hydrogenised matter, and the partial conversion of the same into gaseous compounds, have assumed a porous or cellular condition; while other kinds are schistose and laminated. The porous varieties, like some of the semi-bituminous and steam coals, for instance, exhibit no ligneous structure when examined under the microscope, and the dense, compact, and close-grained varieties, which usually give a conchoidal fracture, afford, likewise, little microscopical evidence of a woody character. In the laminated varieties, which include some of the Wigan cannel and the bituminous class of coals of England and Wales, there are, often, decided impressions of ferns and other plants, while many seams are entirely devoid of them. The bottom clay and the top rock above the coal afford the greatest evidence of the plants which flourished prior to the incarceration of the vegetable beneath the inorganic material.

It is not intended to enter into detail respecting the various plants and trees which have been described as belonging to the carboniferous age, as these are fully delineated in more complete works on the subject. It never was even stated, we think, by any microscopist that all coal exhibits woody structure when examined in thin laminæ, and it is only surprising that so much evidence of vegetable origin should still exist after the changes which have taken place through countless ages. On the other hand, it has been denied recently that coal other than lignite exhibits ligneous structure at all, the only evidence of vegetable origin being the impressions and fossil remains found in the bottom clay and rocky material above the coal. These views are held by the best microscopic botanists, among whom we may mention Sir J. W. Hooker. Lignites such as, for instance, those obtained in our own island at Bovey Heathfield, leave no doubt as to their woody nature; and this character is still retained, not only so far as the grain is considered, but they fracture or split with the grain, and exhibit all the characteristics of wood. Some beds of this variety are, however, very dense and structureless, while there is a bed of lignite, locally known as '*leafy coal*,' which consists entirely of the leaves and stems of plants in a wonderful state of preservation, and capable of being detached and removed from the mass, by careful treatment, in their entire condition.

With regard to the spore theory, or, in other words, the theory that coal is, in very great part, composed of the spores and spore cases of plants—there is little evidence of a weighty character to confirm this hypothesis, while it is evident that could we account for the disappearance of the woody material, it would be, *even then*, very difficult to believe that the immense deposits of coal could be formed by the aggregation of these comparatively minute bodies.

Classification of Coal.—Coal may be divided, both commercially and conveniently, into five classes:—Steam, anthracite, bituminous or house coals, cannel and lignite. The two former are anthracitic in character, and the three latter are bituminous, or, in other words, the two former are characterised by the *low* percentage of hydrogen and oxygen which they contain, and the latter by the comparatively *high* percentage of hydrogen and oxygen.

Steam coal is that variety of coal which, as the name indicates, is so well adapted for raising steam in marine boilers and for steam purposes generally. It is the class of coal for which the South Wales coal field is so famous. Although many of the so-called steam coals answer the purpose which their name conveys, they possess bituminous properties, and belong rightly to that class. The properties so much prized in a good and rightly so-called steam coal is that of giving, practically, no smoke during combustion, while the greater porosity, and rather larger quantity of hydrogen which they possess, confer upon them the property of burning more freely than true anthracite. It is reasonable, too, that this class may and does rightly include a large number of coals which are not, practically, smokeless, and among them many excellent coals can be found which answer all the purposes of the best smokeless, save where, as in the navy, for instance, smoky coal is avoided.

Structure and Character.—The structure of steam coals varies very considerably, like all other classes—some are very dense, hard, shiny, and compact, nearly resembling anthracite, while others are scaly and laminated; others are very compressed in the bed-parallel, and break into cubical or rhombical fragments; others, which include some of the finest samples, are more or less porous and structureless in appearance, and do not fracture readily, but powder and crumble when subjected to much pressure or attrition. The steam coals are characterised by the very large quantity of gas of a combustible nature which they enclose, and consequently require great care and vigilance in their working.

They are found principally in the South Wales basin, in which the 2 ft. 9 in., 4 ft., 6 ft., and 9 ft. veins are those generally worked (when they are found of sufficient thickness and quality), the 4 ft. and 6 ft. veins being usually the most valuable. In the North of England coal-field, the 'low main seam' is the principal bed of steam coal.

Bituminous Coals.—This is by far the most varied class of coal, including, as it does, the greater portion of the coal worked in this country. As house coals, those which burn cheerfully and somewhat freely are most prized.

Structure and Character.—The structure of these coals is extremely varied. Some are very hard and brittle, black and lustrous in appearance, and fracture with the bed or break into rhombical pieces; others are very soft and crumbly, of a dull appearance, and fracture with difficulty, exhibiting a resinous aspect, while others are compact, of a shiny black colour, and scarcely soil the fingers. The bituminous coals of the Northern coal-field comprise some excellent gas coals rich in hydrogen, which possess the property of partially fusing when heated, and yield a coke of excellent quality. Coals of this kind are to be found in the upper veins of the coal measures of the South Wales and Lancashire coal-fields, and throughout nearly every coal-field of Great Britain. The coal-fields of the Midland Counties yield bituminous coals of good quality, some of which do not, however, possess in a high degree the property of caking. Bituminous coals are characterised by the ready manner in which they usually ignite, and burn with a smoky flame. They are found in all the coal-fields of Great Britain.

Anthracite.—This class of coal is commonly termed *stone-coal*, and is also known as *culm*. It is practically smokeless, and on this account much used in passenger steamers and the navy, as also in operations like malt-drying, where its smokeless property is of estimable value. It is also extensively used for smelting, especially in local districts. Owing to its extreme hardness, it does not crumble to powder when broken, and the small, pea-like fragments of purposely broken coal are excellently adapted for raising steam in fast-sailing steamers, and much employed in America for this purpose.

Structure and Character. — Anthracite is of a black, shiny appearance, very hard and compact, and scarcely soils the fingers; it fractures conchoidal across, but usually parallel with the bed. It splinters when heated or broken.

Anthracite is found in the western portion of the South Wales basin, and around Bideford in Devonshire, which was probably a continuation of the South Wales coal-field, but is now separated by the Bristol Channel. There are immense deposits in America, and some of smaller area in Portugal, Sweden, and Ireland.

Cannel Coal.—This variety of coal is very rich in hydrogen, and is capable of yielding, when subjected to destructive distillation, very large volumes of gas of good illuminating power. On this account cannel coal is much valued for gas-making. Numerous shales which possess all the properties of cannel, and are capable of being turned to good account for gas-making, are associated with cannel. They are, however, chiefly used for the manufacture of liquid and solid paraffin. Among them the Boghead cannel is the most important, and this is the variety over which there arose such a conflict of evidence as to whether it should be included under the head of coal. The composition of this variety is given on page 28, and in spite of the last decision given in the celebrated trial referred to, we think it has much more claim to be called coal than many other substances which that term is made to include.

Structure and Character.—Cannel coal is very hard, dense, and structureless, and it resists the action of the atmosphere in a high degree, especially in small masses. On this account it is not unfrequently employed in making ornaments, and some cannels are well adapted for turning and polishing. It splinters when heated, yielding a coke of similar shape to the cannel employed.

Cannel coal is found principally in the Lancashire and Scotch coal-fields. Some cannels of good quality are found in the Flintshire coal-field, and also on the eastern boundary of the South Wales basin.

Lignite is a class of coal little valued in this country. In England there is only one deposit worth mentioning, viz., that at Bovey Heathfield, in Devonshire. Here, however, the best quality has become

ANALYSES OF COAL.

Number	Class	Locality	Composition in 100 parts							Coke	Specific gravity	Analyst
			Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash	Water			
1	Steam Coal	Llwynypia, South Wales .	90·55	4·14	2·35	1·26	0·45	0·67	0·58	85·68	1·310	Author
2	„ „	Merthyr, „ „ .	86·80	4·25	3·06	...	0·83	4·40	0·66	84·42	...	Percy
3	„ „	Pontypool, Monmouthshire	90·63	4·11	2·53	...	0·48	1·65	0·60	88·35	...	Author
4	Anthracite	South Wales . . .	90·39	3·28	2·98	0·83	0·91	1·61	2·00	...	1·392	Vaux
5	„	Pottsville, Penn., U.S. .	90·45	2·43	2·45	...	...	4·67	...	...	1·462	Regnault
6	Bituminous	Aberdare, South Wales .	85·74	4·54	3·57	...	0·81	4·64	0·70	76·1	...	Author
7	„	Northumberland . .	81·41	5·33	7·90	2·05	0·74	2·07	1·35	66·70	1·276	Vaux
8	Cannel .	Wigan	80·07	5·53	8·08	2·12	1·50	2·70	0·91	...	1·276	„
9	„	‘Lesmahago,’ Scotland .	73·44	7·62	11·76	...	1·14	6·03	...	43·3	1·251	Miller
10	„	‘Boghead,’ Edinburgh .	63·10	8·91	7·25	...	0·96	19·78	...	30·23	...	„
11	Lignite .	Bovey Tracey . . .	66·31	5·63	22·86	0·57	2·36	2·27	34·66	30·79	1·129	Vaux
12	„	Komatau, Bohemia . .	66·98	5·06	21·70	0·88	1·15	4·23	16·73	44·16	1·285	Author

The sulphur is not separately determined in No. 5.

The composition per cent. is calculated on the dry samples in Nos. 4, 5, 7, 8, 9, 10, 11, 12, and water is included in Nos. 1, 2, 3, 6.

The nitrogen is included in the oxygen column when not separately determined.

exhausted, and it is only used now for brick-burning, the local potteries having long discontinued its use.

Structure and Appearance.—Some of the lignites are of a distinctly woody character, others again are almost structureless, while more are constituted entirely of the leaves and stems of plants. They are characterised by the large quantity of water which they contain, and by the disagreeable odour which they emit during combustion. This odour, as shown by the author in the paper on lignite gases in the Appendix, is due to the organo-sulphur compounds which are evolved at a comparatively low temperature—the sulphur contained in the coal being partially in organic combination.

Lignite is very widely distributed on the Continent, occurring in immense deposits in Germany and Austria, and it is also found in Italy, Russia, Portugal, Spain, and nearly every country in Europe. In Asia it is found in Burmah and China, and Turkey in Asia; it is discovered in some parts of America, in New Zealand, &c.

CHAPTER II.

GASES IN COAL.—DETERIORATION OF COAL BY EXPOSURE TO ATMOSPHERIC INFLUENCE.

THE gases enclosed in coals have, of late years, received much attention; Marsilly, Dr. Ernest von Meyer, and the author, having carried out numerous experiments with the view of throwing some light upon the question of the formation of coal, and upon that still incomplete enquiry, the nature of atmospheric influence upon the deterioration of coal. All coal contains gas enclosed within its pores or interstices, the nature of these gases varying with the character of the coal and the geological age to which it belongs. A great number of interesting experiments were carried out by Dr. Meyer, but we shall confine ourselves, in the present treatise, to those more particularly relating to the coals examined from the North of England coal-field.

As pointed out by the author (p. 330, Appendix), the method which Dr. Meyer adopted for the withdrawal and collection of the gases from coal was open to some objection. Beyond the difficulty of collecting gases over water, there is no chance of proving that the gases so collected are the same as those which would be evolved at the ordinary temperature of the atmosphere. The contact of hot water with the coal, and its subsequent access to the interior portions, may have the effect of modifying the evolution of the gases, and there is a probability that even the character of the gas may be modified. It will be seen, readily, that there is considerable difficulty attached to the collection of the gases enclosed in coal, on account of the tendency of the air to become mixed with them. The method employed by the author, although free from the objections mentioned, is not, nevertheless, all that might be desired. During the removal of the air from around the coal and the formation of a vacuum, some gas escapes, but the method adopted of subjecting to analysis the last portion of air exhausted during the formation of a vacuum at the ordinary temperature, furnished the means of calculating the quantity of gas so evolved. The nature of the gas occluded in coal depends, not so much upon the structure of the coal as upon the conditions under which its formation has taken place, and the depth below the surface at which the coal is situated. According to Marsilly[1] 100 grams of coal evolved from 100 to 200 cubic centimetres of gas at 300° C. (572° F.), or, in other words, one pound of coal evolves from 28 to 56 cubic inches of gas when heated at a temperature of 572° F. (300° C.). Marsilly also states that, after exposure to the atmosphere for six months all the gas escapes, and that then even by heating the coal to 300° C. (572° F.) no gas can be obtained. It is evident that Marsilly has not examined coals of an anthracitic character, or he would, in the first instance, have found much more gas than he mentions; and in the second place, he must be mistaken respecting the absence of gas in coal which had been exposed for six months. After the exposure of coal to the atmospheric influence for six years, the author has found it to contain gas, and the result of a number of unpublished experiments, carried out with a view to throw light upon this matter, has tended to confirm the previous investigations in this direction. Hard, close-grained, compact varieties retain their enclosed gases with little admixture of oxygen for a great length of time, while porous coals naturally lose their occluded gas more readily, but never altogether, carbonic acid being always present. These results are corroborated by Dr. Meyer.

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[1] *Annales des Mines.*

Marsilly further states that 'The gases evolved from coal in pits liable to fire-damp consist, almost entirely, of marsh-gas, while the gas from coal obtained in mines where no fire-damp is found consists chiefly of nitrogen.' To a certain extent this is true, but it is not always the case. According to the law of diffusion, and the law of transpiration of gases, marsh-gas, being the lightest gas which is imprisoned in the interstices of the coal, should, and does escape, more quickly than any other. As a consequence, therefore, the gases evolved in a mine, and which are included under the head of *fire-damp*, consist chiefly of marsh-gas. This rule, however, only holds good in mines which are situated in a fiery part of a coal-field, and in which the coal holds enclosed an enormous volume of explosive gas,—such as the steam coals of the South Wales and North of England coal-fields, and some of the Wigan coals. As a seam or vein becomes more and more bituminous in character, or as we pass from the anthracite to the bituminous seams in the coal-fields referred to, we meet with an intermediate class of coal which evolves some marsh-gas, but, in addition, an appreciable quantity of carbonic acid and nitrogen.

In the true bituminous—that numerous class of house coals—the quantity of marsh-gas given off in the mines in which these coals are worked does not bear an exact ratio to that of the carbonic acid and nitrogen, while in the majority of instances marsh-gas is almost, if not entirely, absent. When this is the case, nitrogen, it is true, forms a large proportion of the enclosed gas, but the percentage of carbonic acid is always so considerable that it must be regarded in association with the nitrogen.

In the gases enclosed in Scotch cannels and lignites, carbonic acid takes the entire lead, so that it might be said, with equal justice, that coals evolve carbonic acid for the most part in mines free from fire-damp. It is not safe, however, to draw any fast line as to the nature of the gases evolved in fiery and non-fiery mines, as they vary considerably.

The Zwickau coals examined by Dr. Meyer were, apparently, entirely different in character, so far as the enclosed gas is concerned, from any examined by the author; while the results obtained with the Westphalian coals are not dissimilar to those of the English semi-bituminous, and some of the cannel coals. (See Tables.) Dr. Meyer investigated the nature of the gases enclosed in eight samples of English coal from the North of England coal-fields, TABLE SHOWING THE AMOUNT AND COMPOSITION PER CENT., BY VOLUME OF THE GAS EVOLVED FROM CERTAIN SAXON AND WESTPHALIAN COALS AT 20° C.

Locality	Number of Cubic Centimetres of Gas yielded by 100 grams. of Coal at 20° C.	Composition of the Gas						
		Carbonic Acid	Oxygen	Nitrogen	Marsh gas	Hydride of Ethyl	Gases absorbable by Sulphuric Acid	Carbonic Oxide
ZWICKAU.								
1. 'Schichtenkohle,' (name of seam) 700 metres deep. Fresh winning. Very compact, markedly schistose or slate-like in structure.	38·0	2·42	2·51	23·17	71·90	...	...	...
2. (*a*) 'Schichtenkohle,' 690 metres deep. Had been exposed during five years to the ventilation air-current of the pit. Similar in appearance to the last.	18·2	16·70	4·90	55·15	3·17	18·61	1·47	...
(*b*) 'Schichtenkohle,' 690 metres deep. Gas collected a week after *a* had been collected.	...	11·40	3·80	60·98	3·44	18·88	1·50	...
(*c*) 'Schichtenkohle,' 690 metres deep. Gas collected a fortnight after *b* had been collected.	...	12·10	1·10	65·16	3·19	16·85	1·60	...

(*d*)* 'Schichtenkohle,' 690 metres deep. Gas collected 3 or 4 months after *c* had been collected, during which time the coal was left in a cool dry place.	...	12·91	2·57	57·84	4·06	22·68	...	...
(*e*)* A portion of the same coal as *d*, in pieces of the size of nuts, was kept heated to 45° C. with free access of air, and then treated in the same manner as in all the other cases to expel the gas, which escaped not notably more slowly than from the same coal which had not been heated.	...	10·65	3·20	74·72	...	9·80	1·63	..
(*f*)* From Zwickau. Name of seam unknown. Very compact and hard, with bright conchoidal fracture. Used for gas-making at Leipzig.	34·7 (at 15° C.)	2·71	0·16	29·39	59·61	7·68	0·45	...
(*g*) From Zwickau. Name of seam unknown. Gas evolved by the usual treatment, after the coal had been previously heated during twenty-four hours at a constant temperature of 50° C.	...	15·60	3·10	73·12	...	2·04	$\left\{\begin{matrix}C_3H_8\\4·39\end{matrix}\right\}$	1·75
3. 'Zachkohle' (name of seam), 680 metres deep. Fresh winning. Schistose, composed of bright and dull layers of pitch-coal (*Pechkohle*).	25·5	4·02	0·62	50·36	45·00	...	...	...

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* 2, *d*, *e*, and *f* are reported in the *Journal für praktische Chemie*, 1872, cxiii. 416.

TABLE SHOWING THE AMOUNT AND COMPOSITION OF GAS, &c.—*Continued.*

Locality	Number of Cubic Centimetres of Gas yielded by 100 grams. of Coal at 20° C.	Composition of the Gas						
		Carbonic Acid	Oxygen	Nitrogen	Marsh-gas	Hydride of Ethyl	Gases absorbable by Sulphuric Acid	Carbonic Oxide
ZWICKAU, *continued.*								
4. 'Zachkohle,' 656 metres deep. Had been exposed during 1½ year to the ventilation air-current of the pit. It showed traces of weathering, but internally its fracture was bright.	18·6	2·25	0·70	23·89	73·16	...	...	...
'Lehekohle' (name of seam), 560 metres deep. Fresh winning. Hard, irregularly schistose, with bright fracture.	52·8	0·60	trace	48·00	51·40	...	...	...
6. (*a*) 'Lehekohle,' 690 metres deep. Had been exposed during five years to the ventilation air-current of the pit. Appeared outwardly weathered, brittle, not particularly schistose.	13·6	7·62	2·44	50·75	15·88	22·35	0·96	...
(*b*) 'Lehekohle,' 690 metres deep. Gas collected a week after *a* had been collected.	...	10·10	2·60	50·53	10·18	23·32	1·45	1·82

(*c*) 'Lehekohle,' 690 metres deep. Gas collected two months after *b* had been collected.	...	11·18	2·82	67·99	...	16·36	1·65	...
FROM THE 'PLAUEN'SCHE FORMATION.'								
7. 'Harter Schiefer' (local name). Evolved gas copiously. This and the two following were freshly gotten, and from the same pit, named 'Burgk.'	not determined	48·7	1·8	49·5	...	...	...	...
8. 'Weicher Schiefer' (local name). Lively evolution of gas.	do.	38·2	1·2	60·6	...	...	...	...
9. 'Maschinenschiefer' (local name). Evolved gas most copiously of the three.	do.	54·9	1·2	43·9	...	...	...	...
All these coals (7, 8, 9) were rich in disseminated iron-pyrites; they were greyish black, and lacked the lustre and blackness of true carboniferous coals.								
WESTPHALIA.								
10. From the 'Zollverein' pit, near Essen.	22·5	7·50	2·59	89·91	...	...	...	...
11. From the 'Consolidation' pit, do.	17·4	2·56	4·11	58·48	24·85	...	...	...
Both of these coals (10, 11) were true fat coals, much valued for gas making.								

TABLE SHOWING THE AMOUNT AND COMPOSITION OF GAS, &c.—*Continued.*

Locality	Number of Cubic Centimetres of Gas yielded by 100 grams. of Coal at 20° C.	Composition of the Gas						
		Carbonic Acid	Oxygen	Nitrogen	Marsh-gas	Hydride of Ethyl	Gases absorbable by Sulphuric Acid	Carbonic Oxide
WESTPHALIA, *continued.*								
12. (*a*) 'Sonnenschein' seam, near Bochum. Distinctly laminated, with here and there iron pyrites. Freshly gotten.	50·6	4·87	2·66	75·82	16·65	...	...	...
(*b*) 'Sonnenschein' seam, near Bochum. Had been exposed during a year to the ventilation air-current of the pit.	43·2	11·12	2·88	78·60	7·40	...	...	...
13. (*a*) 'Dickebank' seam, near Bochum. Very like No. 12*a*. Freshly gotten.	43·3	2·18	2·12	70·51	25·19	...	...	...
(*b*) 'Dickebank' seam, near Bochum. Had been exposed during a year to the ventilation air-current of the pit.	41·2	15·84	3·06	74·53	6·57	...	...	...
14. (*a*) 'President' seam, near Bochum. Not distinctly schistose, easily friable. Freshly gotten.	59·2	5·82	1·99	60·62	31·57	...	...	...

(*b*) 'President' seam, near Bochum. Had been exposed during a year to the ventilation air-current of the pit.	43·6	7·68	2·24	86·77	3·31	...	...	...
15. (*a*) 'Wilhelm' seam, near Bochum. Not distinctly schistose, here and there fibrous, with lustre of graphite. Freshly gotten.	54·4	1·30	1·60	66·85	30·25	...	...	...
(*b*) 'Wilhelm' seam, near Bochum. Had been exposed during a year to the ventilation air-current of the pit.	39·2	4·35	3·35	81·18	11·12	...	...	...
16. (*a*) 'Franziska' seam, near Bochum. Distinctly schistose, rich in iron pyrites. Freshly gotten.	54·5	2·02	0·90	86·43	10·65	...	...	...
(*b*) 'Franziska' seam, near Bochum. Had been exposed during a year to the ventilation air-current of the pit.	39·6	2·15	3·14	91·28	3·43	...	...	...
17. (*a*) 'Leonhard' seam, near Bochum. Distinctly schistose, and contains iron pyrites. Freshly gotten.	42·0	3·72	0·39	90·19	5·70	...	...	...
(*b*) 'Leonhard' seam, near Bochum. Had been exposed during a year to the ventilation air-current of the pit.	3·64	8·49	3·57	87·94	trace	...	...	...
All the specimens from No. 12 to 17 inclusive were from the 'Constantine the Great' colliery, and in this Table they are arranged in the order of their geological age, beginning with the oldest, No. 12.								

TABLE SHOWING THE AMOUNT AND COMPOSITION PER CENT., BY VOLUME OF THE GAS EVOLVED FROM CERTAIN COALS OF NORTHUMBERLAND AND DURHAM (20° C.).

Locality of the Coal, Northumberland and Durham	Number of cubic centimetres of Gas yielded by 100 grammes of Coal	Composition of the Gas				
		Carbonic Acid	Oxygen	Nitrogen	Marsh-gas	Character of the Coal
1. From the Low Main Seam, Bewicke Main Colliery.	25·2	5·55	2·28	85·65	6·52	Weathered externally.
2. From the Maudlin Seam, Bewicke Main Colliery.	30·7	8·54	2·95	61·97	26·54	Very hard, bright, with conchoidal fracture.
3. From the Main Coal Seam, Urpeth Colliery.	27·0	20·86	4·83	74·31	...	Bright fracture.
4. From the 5-Quarters Seam, Urpeth Colliery, about 30 fathoms from the surface.	24·4	16·51	5·65	77·84	trace	Bright fracture.
5. From the 5-Quarters Seam, Wingate Grange Colliery; 74 fathoms from the surface.	91·2	0·34	trace	13·86	85·80	Here and there fibrous in structure.
6. From the Low Main Seam, Wingate Grange Colliery; 108 fathoms from the surface.	238·0	1·15	0·19	14·62	84·04	
7. From the Harvey Seam, Wingate Grange Colliery; 148 fathoms from the surface.	211·2	0·23	0·55	9·61	89·61	Very hard, containing iron pyrites, with bright conchoidal fracture.
8. From the Upper or Harvey Seam, Woodhouse Close Colliery; 25 fathoms from the surface.	84·0	5·31	0·63	44·05	50·01	

and the preceding tables show the results which he obtained, as also those from the German coals.

A tabulated statement of the results obtained by the author is given for comparison (see pp. 42–47).

As will be seen from the table of the gases enclosed in the North of England coals, Dr. Meyer describes the external character of the coal, but whether they are bituminous or anthracite is not mentioned. 1, 2, 3, 4, 5, 8 are apparently (judging from the nature and quantity of the enclosed gases), bituminous and semi-bituminous, and 6 and 7 are anthracitic, or what may be termed steam coals. The gases in the North of England coals are similar to those which had been previously shown to be present by Dr. Playfair and others in blower gases and fire-damp, and similar to those found by the author in the bituminous and steam coals of the South Wales basin. In fact, if such a proof were wanting, the determination of the enclosed gases in the coals of the North of England coal-fields, and in those from the South Wales coal-field, would go a long way to establish the possibility of the period and conditions of formation being at one time and alike.

At first sight there appears to be a very great difference between the composition of the gases which were obtained from the coals examined either by Dr. Meyer or the author when compared with the analyses of fire-damp, but when it is considered that the coals had lost by far the greater portion of gas before being subjected to investigation, and that by far the largest portion which escaped consisted of marsh-gas, it will readily be understood that the

TABLE SHOWING THE QUANTITY AND COMPOSITION OF THE GAS EVOLVED IN VACUO FROM VARIOUS COALS AT 100° C. (212° F.), UNLESS OTHERWISE STATED.

Name of Seam, Nature of Coal, &c.	Number of cubic centimetres of gas evolved by 100 grammes of Coal	Composition of the Gas						
		Carbonic Acid	Oxygen	Nitrogen	Marsh-gas	Hydride of Ethyl	Quartane, or Ethyl	Hydride of Propyl
SOUTH WALES COALS.								
1. No. 1 vein, bituminous, from a level in side of the mountain. Plymouth Iron Works, Merthyr district.	55·9	36·42	0·80	62·78	...	...	...	...
2. No. 3 vein, do.	61·2	16·77	2·72	80·11	0·40	...	...	...
3. No. 3 vein, Rhondda, from Cwm Clydach, bituminous.	55·1	5·44	1·05	29·75	63·76	...	...	...
3*a*. 'Abergorki' vein; side of the mountain. Bute Merthyr Colliery, Rhondda District, semi-bituminous.	73·6	12·34	0·64	14·51	72·51	...	...	...
4. '2 ft. 9 in. vein.' Bute Merthyr Colliery, Rhondda District; 100 yards deep. Steam coal.	194·8	5·04	0·33	7·33	87·30	...	...	...
5. 'Upper 4 feet vein.' Navigation Colliery, Aberdare District; 400 yards deep. Steam coal.	250·1	13·21	0·49	4·66	81·64	...	...	...

6. ‘Upper 4 feet vein.’ Dunraven Colliery, Rhondda District; 206 yards deep. Steam coal.	218·4	5·46	0·44	9·88	84·22	...	...	...
7. ‘Upper 4 feet vein.’ Cyfartha Colliery, Merthyr District; 180 yards deep. Steam coal.	147·4	18·90	1·02	12·61	67·47	...	...	...
8. ‘6 feet vein.’ Bute Merthyr Colliery, Rhondda District; 140 yards deep. Steam coal; hard, laminated.	375·4	9·25	0·34	3·49	86·92	...	...	...
After exposure to the atmosphere, in walnut-size pieces, for 14 weeks.	112·3	11·75	2·64	30·83	54·78	...	...	...
9. ‘6 feet vein.’ Dunraven Colliery, Rhondda District; 225 yards from the surface. Steam coal; soft, porous.	149·3	11·35	0·56	14·62	73·47	...	...	...
10. ‘9 feet vein.’ Duffryn Colliery, Aberdare District. Steam coal.	215·4	5·64	0·54	11·12	82·70	...	...	...
11. ‘Bettwys coal;’ bituminous. Ogmore valley.	24·0	22·16	6·09	69·07	2·68	...	...	...
12. ‘Llantwit coal;’ bituminous, laminated, brittle.	39·7	9·43	2·25	56·34	31·98	...	...	...
The same portion of coal, after removal from Sprengel pump, was left exposed to the air for 10 weeks, again connected, and treated as before for 7 hours.	31·2	18·62	7·94	65·58	7·86	...	...	...

TABLE SHOWING THE QUANTITY AND COMPOSITION OF GAS, &c.—*Continued.*

Name of Seam, Nature of Coal, &c.	Number of cubic centimetres of gas evolved by 100 grammes of Coal	Composition of the Gas						
		Carbonic Acid	Oxygen	Nitrogen	Marsh-gas	Hydride of Ethyl	Quartane, or Ethyl	Hydride of Propyl
13. Anthracite from Bonvilles Court Colliery, Pembrokeshire; very hard and compact.	555·5	2·62	...	4·25	93·13	...	...	...
14. Watney's Llanelly anthracite; very compact heated at 100° C. (212° F.) for 7 hours.	600·6	14·72	...	1·10	84·18	...	...	...
The same portion of coal was further heated at 200° C. (392° F.) for 8 hours.	993·1	8·06	...	0·11	91·83	...	...	...
The same portion of coal was further heated to 300° C. (572° F.) for 8 hours.	206·5	1·43	...	0·10	98·47	...	...	...
Another portion of the coal was heated at 100° C. (212° F.) for 21 hours, and let stand in vacuo for 70 hours.	731·1	...	...	...	...	...	...	...
Analysis of the gas evolved during the first hour, 100° C. (212° F.).	...	14·60	...	4·06	81·34	...	...	...
Analysis of the gas evolved after heating for 3 hours, 100° C. (212° F.).	...	13·91	...	3·64	82·45	...	...	...
15. 6 feet vein (probably). Llwynypia Colliery, Rhondda District. Steam coal; somewhat porous fresh from colliery in large lump.	...	18·80	trace	1·90	75·35	3·95	...	...

Same lump of coal after exposure for three days.	...	18·61	trace	4·03	68·66	8·70	...	...
CANNEL COAL.								
1. '5/3 seam,' from Wigan Arley Mine, Lancashire coal field; 350 yards. Wigan cannel.	421·3	6·44	...	8·12	80·69	4·75	...	...
2. '3/2 seam,' from Lancashire coal field. Wigan cannel; 600 yards deep; curiously laminated, very hard.	350·6	9·05	...	5·96	77·19	7·80	...	...
Last portion of gas exhausted and brought over by the Sprengel pump after heating for two days.	...	3·97	...	1·13	78·58	15·32	...	...
The same portion of cannel was heated at 200° C. (372° F.), but too much oily matter present for analysis.	276·2	...	...	...	...	...	...	...
3. Heywood cannel, Wilsontown, Lanark, Scotland.	16·8	53·94	...	46·06	...	trace	...	...
4. Lesmahago cannel	55·7	84·55	...	14·54	...	...	...	0·91
5. Cannel shale, Lasswade, Edinburgh .	15·7	68·75	...	28·58	...	2·67	...	...
JET.								
6. Whitby jet, finest quality, for ornaments	30·2	10·93	...	2·17	...	...	86·90	...

Table showing the Quantity and Composition of the Gas Evolved in a Vacuum from Lignite and Mineral Resin at different Temperatures.

Name, character of Substance, &c.	Number of cubic centimetres of Gas yielded by 100 grammes of Coal	Composition of the Gas							
		Carbonic Acid	Oxygen	Nitrogen	Carbonic Oxide	Marsh-gas	Hydride of Propyl	Olefiant Gas and gases of the same series	Sulphuretted Hydrogen
1. (*a*) 'Leafy coal,' from Bovey Heathfield, Devonshire; consists of the leaves and stems of plants; gas obtained by heating substance in a vacuum at 50° C. (122° F.).	56·1	87·25	0·24	8·92	3·59	...	...	...	...
(*b*) Same portion of lignite, heated at 100° C. (212° F.)	59·9	89·53	...	5·03	5·11	...	...	0·33	...
(*c*) Same portion of lignite, heated at 200° C. (392° F.).	18·0	88·39*	...	0·46	8·83	...	...	2·32	...
(*d*) First part of gas collected . . .									
(*e*) Second part of gas collected . .	...	82·06	...	0·15	14·00	...	...	0·97	2·82
(*f*) Same portion of lignite, heated at 250° C. (482° F).	...	71·13	...	0·27	16·20	5·46	...	1·09	5·85
2. (*a*) Lignite (woody) from Bovey Heathfield, Devonshire, heated in a vacuum at 50° C. (122° F.)	48·5	...	...	...	...	...	...	...	...
(*b*) First portion of gas collected at 50° C. (122° F.).	...	79·12	0·51	16·23	4·14	...	...	trace	...

(*c*) Second do.	...	96·62	0·33	...	...	...	...	...	...
(*d*) Third do.	...	97·29	0·21	1·10	1·40	...	...	trace	...
(*e*) Fourth do.	...	96·10	0·19	0·78	2·93	...	...	trace	...
(*f*) Fifth do.	...	96·23	0·11	1·24	2·42	...	...	trace	...
(*g*) Same lignite heated at 100° C. (212° F.) 1st portion.	114·3	96·74	...	0·46	2·80	...	...	...	...
(*h*) Second portion of gas obtained at 100° C. (212° F.).		96·05	...	0·42	3·20	...	...	0·33	...
(*i*) Third do.		95·34	...	0·22	3·83	...	...	0·61	...
(*k*) Same lignite heated at 200° C. (392° F.)	...	86·30	...	0·34	7·41	3·34	0·53	2·08	...
3. Lignite from Bovey Heathfield, Devonshire, heated in a vacuum at 50° C. (122° F.).	68·1	...	...	...	...	...	...	...	...
(*a*) First portion of gas collected at 50° C.	...	94·12	0·28	3·47	2·13	...	...	trace	...
(*b*) Second do.	...	98·30	...	0·35	1·35	...	...	trace	...
(*c*) Third do.	...	98·27	...	0·39	1·15	...	...	0·19	...
(*d*) Same portion of coal heated at 100° C. (212° F.).	86·3	97·77	...	0·33	1·69	...	...	0·21	...
(*e*) Same portion of coal heated at 200° C. (392° F.).	...	91·68	...	0·38	7·12	...	...	0·41	0·41
4. (*a*) 'Mineral Resin,' from Bovey Heathfield, Devonshire; heated at 100° C. (212° F.) in a vacuum.	21·4	88·24	0·23	3·16	7·90	...	...	0·47	...
(*b*) Some portion of substance, heated at 160° C.	180·0	78·88	...	0·31	7·82	8·05	1·86	2·67	0·41

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* This volume contains a little sulphuretted hydrogen left undetermined.

relative percentages of the other gases must be much increased, as shown in the results obtained. When Dr. Meyer's results are compared with those of the author, it will be seen that the relative proportion of carbonic acid and nitrogen are dissimilar. This possibly may be accounted for by the method employed by Dr. Meyer, viz. collecting the gases over water. This circumstance is alluded to on account of the importance which Dr. Meyer attaches to the determination of carbonic acid and nitrogen in order to show the origin of the latter gas, and to combat the theory of Bishof, who maintained that the enclosed nitrogen (gaseous nitrogen) of coal was derived, not from atmospheric air, but in the ordinary process of coal forming,—the combined nitrogen being set free by the gradual decomposition of nitrogenous material. As this is a very interesting point connected with the subject, a few remarks will be made thereon. Dr. Meyer mentions that 'there is no substantial evidence to prove that free nitrogen is generated in the natural process of decay,' and as he found less oxygen combined with carbon as carbonic acid than corresponded to the quantity of nitrogen present in the enclosed gases, he inferred that the nitrogen was derived from atmospheric sources; and that the remainder of the oxygen corresponding to the nitrogen (as air) was absorbed by the coal. In order to render this most intelligible, it will be necessary to consider the proportions required. Carbonic acid occupies two volumes, and nitrogen one volume (compared with hydrogen), and as carbonic acid contains two volumes of oxygen, the ratio of the oxygen in carbonic acid to free nitrogen will be volume for volume. Atmospheric air contains approximately 4 parts of nitrogen and 1 part of oxygen by volume; it follows, therefore, that if the enclosed nitrogen of coal were derived from air, the proportion of that gas to carbonic acid (assuming that the oxygen was used in forming carbonic acid) should be as 4 is to 1. In the majority of instances Dr. Meyer found that the ratio of the nitrogen to the oxygen was greater than this, and inferred from the experiments of other chemists, that the excess of oxygen may have gone to oxidise hydrogen, or have entered into combination with the coal. As already observed, the ratio of the carbonic acid to the nitrogen in the author's results of the gases enclosed in coals from the South Wales basin does not tend to support Dr. Meyer's conclusions; on the contrary, with the exception of one or two instances, no such ratio exists, the percentage of carbonic acid being in some cases much greater than the nitrogen. When the cannel coals are taken into consideration—and these are as true carboniferous as the others—the ratio of the nitrogen to the carbonic acid is entirely altered, as the latter gas always exceeds the former. Again, with regard to lignite, we encounter the same circumstance, because the enclosed gases consist mainly of carbonic acid, which is present in quantity ten times as great as nitrogen. Assuming, however, that the carbonic acid and nitrogen did exist in the enclosed gases in the ratio we have mentioned—that is, 1 part of the former and 4 parts of the latter—it does not follow that the nitrogen was derived from atmospheric sources, because a corresponding quantity of oxygen, combined in the form of carbonic acid, was present. In Dr. Meyer's results of the Zwickau coals, which most conform to what he deduces, the depth from which the coals were won—from 600 to 700 metres (650 to 760 yards), seems to show that they were removed from the action of both water and dissolved oxygen, and, with the exception of that which found its way to the coal material previous to its being buried under such a mass of inorganic matter, no air could reach it. The same is true with regard to most of the coals which contain much marsh-gas—the steam coals, for instance. When these are situated below the reach of water, and contain, as they do, enormous volumes of gas stored up under a pressure of 50 or even 100 atmospheres, it is evident that no air can gain access to the coal. Then, again, there is no direct evidence to prove that nitrogen is *not* generated in the ordinary process of decay. It is said to be generated in small quantity in the animal economy during the slow combustion of food to supply animal heat, and it is extremely probable, too, that nitrogenous substances in the act of undergoing putrefaction or decay evolve free nitrogen, as well as nitrogen combined with hydrogen in the form of ammonia. Ammonia is not found in coal to any perceptible extent, and it is only rational to assume that it is not a product of the slow decomposition of nitrogenous matter in the coal beds—nitrogen is set free, and constitutes, doubtless, that found, especially, in deep coals. It is very probable that in the majority of instances the more readily oxidisable nitrogenous principles of plants and leaves may have been brol [illegible] e the vegetable material from which coal is produced became buried under any considerable thickness of inorganic matter, but there does exist, in coal, nitrogenous compounds which have resisted decomposition until now, and such compounds as are calculated to yield, by very slow decomposition, the free nitrogen which the coals referred to contain. If, too, we are to regard the nitrogen enclosed in coal as being derived from atmospheric air, then it follows that those seams or veins of coal nearest to the surface should contain the largest quantity. The author's experience does not tend to confirm this rule; on the contrary, bituminous coals worked in 'levels' in the sides of mountains, or at a small depth from the surface, usually contain their enclosed carbonic acid and nitrogen in the proportion of from one to two or three, while the lignites, which are worked comparatively close to the surface, contain the above gases in the proportion of ten carbonic acid to one nitrogen. The bituminous coals and lignite situated near the surface, more especially the latter variety, contain a very large proportion of water; and, although there is no reason to assume that the nitrogen is derived from that dissolved in the water which finds its way to the coal, it is very probable that the oxygen which is dissolved in the water in much larger quantity helps to oxidise the carbon to carbonic acid. Then, again, in the deep coals it is very probable that the carbon of the carbonic acid has been oxidised at the expense of the combined oxygen of the organic matter. Volume for volume, the quantity of nitrogen in deep steam coals is often equal to that present in bituminous varieties found close to the surface.

Assuming, what appears to be correct, that 6 in Dr. Meyer's table, page 40, was a steam coal obtained at a depth of 216 yards from the surface, and that 3 in the same table is a bituminous coal, the total volume of nitrogen in 6 exceeds that in 3. The total gas obtained from 6 was 238 c. c., containing 14·62 per cent. of nitrogen. 100 grams of this coal therefore enclosed 34·8 c. c. of nitrogen, or, taking the specific gravity of the coal as 1·3, then 100 cubic feet of the coal contain 45·2 cubic feet of nitrogen. The total gas obtained from 3 was only 27 c. c. per 100 grams of coal, which, as will be readily seen, is much less *in toto* than the nitrogen in 6.

The conclusions of Bischof regarding the origin of nitrogen in coal, and its being derived from the decomposition of the organic material from which coal is produced, are equally, if not more tenable, than the deductions of Dr. Meyer respecting the atmospheric origin of the nitrogen of coal.

The gases enclosed in the steam coals are present therein under immense pressure. Some idea of this pressure may be obtained from the comparison given on p. 353, Appendix. Assuming that the gases enclosed in coal escape therefrom somewhat in accordance with the law of diffusion, or rather the law of the transpiration of gases, it follows that coal No. 6 must have lost a very large proportion of its gases, as shown when the analysis of the gas obtained by boring into the coal is compared with that of the actual gases taken from the coal itself, thus:—

	A. Gases exhausted in a vacuum from the coal itself.	B. Gases obtained by boring a hole into the coal.
Carbonic acid	5·46	0·44
Marsh-gas	84·22	96·54
Oxygen	·44	—
Nitrogen	9·88	3·02
	100·00	100·00

According to the law of the transpiration of gases, the velocity of transpiration of the gases in analysis B would be, according to Graham ('Elements of Chemistry')—

Carbonic acid	1·37
Marsh-gas	1·815
Nitrogen	1·141

Oxygen is taken as the standard of comparison, and is represented by unity 1·000.

Now, if the gases which constituted the mixture represented by analysis B escaped, as they did most probably somewhat in accordance with the above velocities, the analysis B does not represent the composition of the original or primary enclosed gas in the coal. An approximate idea of its composition may be obtained thus: divide the percentage of each gas by its respective velocity of transpiration, then we have—

Carbonic acid	0·32
Marsh-gas	53·19
Nitrogen	2·65
Making a total of	56·16

Bring the above figures into percentages by dividing by 56·16 and multiplying by 100, we have the following figures—

Carbonic acid	0·57
Marsh-gas	94·71
Nitrogen	4·72
	100·00

as the composition of the original gas present in the solid coal within four feet of the working face. How much gas had escaped previous to sample B being collected, is a question that cannot be answered with the slightest approximation to accuracy. It was doubtless very appreciable. However, putting aside primary loss, and taking the above figures as representing the composition of the original enclosed gas, and analysis A as representing the gases enclosed in the lump of coal from which the gases were exhausted, how many times its volume of gas would the coal contain previous to its being cut from the seam? Knowing the volume of gas which A measured, viz. 218·4 c. c. per 100 grams of coal, and taking the velocity of transpiration of the gases as before, then it is evident that the total quantity of gas originally present must have reached an astounding figure. See p. 295.

A very curious circumstance connected with the gases in coals is the manner in which they are evolved in a vacuum. The velocity of transpiration of nitrogen is much less than that of marsh-gas or carbonic acid, yet the former gas appears to be evolved *in vacuo* with greater rapidity than either of the latter. This may be seen in the results obtained with the various coals as given in the Appendix.

Dr. Meyer states 'That the results of his experiments do not show variations corresponding to the geological age of the coal, or, as would be anticipated, show that more recent deposits contain the most gas.' Now the quantity of the enclosed gas in coal does not depend so much upon the geological age as upon the depth which the coal is situated beneath the surface and the character of the earthy strata under which it is buried. If the character of the material above the coal is of a dense nature, free from dislocations and impermeable to water and air, the gases generated during the decompositions of the coaly matter will become imprisoned, and will be present under much pressure and in large quantity. On the other hand, if the material under which the coal is buried has been subjected to volcanic or other disturbing influence, and the depth thereof is not very considerable, then the gases generated during the process of change will find a more ready exit, and, as a matter of course, will not be present under much pressure or in large quantity. It has been already shown, too, that the quantity of gas enclosed in coal is dependent upon the nature of the decomposition which has taken place, and in those cases where the hydrogen has combined with carbon to form marsh-gas the volume of enclosed gases is usually very large. So far as the lignites have been examined, there does appear to be a decided difference between their enclosed gas and that present in coals of the carboniferous formation. Some two specimens of lignite from Bohemia were examined by Zitowitsch, who found carbonic oxide as one constituent of the enclosed gases. The author also found carbonic oxide in appreciable quantity in the lignites of Bovey Heathfield, in Devonshire. With the exception of one instance recorded by Dr. Meyer, in which he found that this gas had made its appearance in a coal after exposure for a week to the atmosphere, carbonic oxide has not been detected in coals other than lignite, and this coincidence is a somewhat characteristic difference between the coals of the carboniferous and tertiary ages. So far, too, hydrocarbon gases are either absent or found in lignites in traces only, the enclosed gases consisting almost entirely of carbonic acid and carbonic oxide, with a little nitrogen.

The immense volumes of gas which are constantly evolved by blowers on the surface, as well as in the workings of coal mines, must drain the seams of coal of much of their enclosed gas. There are numerous instances of blowers, both in the North of England and South Wales coal fields, which have found their way to the surface through natural channels. The analysis of one of these from the Cwm Park brook is given on page 351, Appendix, and from its composition it is doubtless fed by one or more of the veins of steam coal which lie beneath. When the natural fissures or exits are numerous, the seams of coal from which they drain the gas are not nearly so fiery, and the actual quantity of gas enclosed in the coal is naturally comparatively low. It not unfrequently happens, especially in working a mine in a virgin locality, that powerful blowers make their appearance, and are sometimes the cause of dangerous explosions. These supplies of gas may soon become exhausted, or they may continue to evolve fire-damp, with no apparent interruption save the influence of barometric changes, for long periods of time. In the latter case, the gas is usually confined and led off by a pipe to the surface, where it is sometimes utilised for lighting the top of the downcast shaft, &c., at night. The blower at Llwynypia Colliery in the Rhondda Valley, the analysis of which is given on page 351, Appendix, is conveyed from the mine to the surface, and the supply which has lasted several years, does not, even now, show any signs of becoming exhausted. The composition of the gases of this blower differs somewhat from that of the others recorded, as it contains a small percentage of hydride of ethyl (C_2H_6). Some two years after making the analysis of the blower gas, the author determined the enclosed gases in a sample of steam coal from the Llwynypia Colliery, and obtained so large a percentage of hydride of ethyl as to leave no doubt of its presence. There is reason to believe that the blower is fed from the seam of coal so examined, and thus accounts for the presence of hydride of ethyl in the gas. This colliery is situated near the centre of the South Wales basin, and the gas has not been drained off to any great extent. The excellent steam coal won in this colliery contained enclosed gases of the following composition:—

	1.	2.
Carbonic acid	18·80	18·61
Oxygen	trace	trace
Marsh-gas	75·35	68·66
Hydride of ethyl	3·95	8·70
Nitrogen	1·90	4·03
	100·00	100·00

No. 1 was obtained from the coal fresh from the colliery; No. 2 from the same lump of coal after three days' exposure. It is very probable, therefore, that if the coals which are situated in this part of the South Wales basin were examined, hydride of ethyl would be found to be a constituent of many of them.

The greater number of the blowers, which are usually short-lived, make their exit through cracks in the rock a few feet in the rear of the working face of the coal. These are chiefly fed by the coal in the immediate vicinity, the cracks in the rock affording an outlet. As the working face proceeds onward, the blowers follow—the old ones dying out successively. Sometimes, however, if there is an unworked seam of coal above, a communication is opened up therewith through the fracture and subsequent fall of the top rock; in such cases the blower may long continue to evolve gas.

Deterioration of Coal.—The effect of the exposure of coal to atmospheric influence is a very important consideration, and one which, although it has been made the subject of repeated investigation, is not by any means complete, the results obtained being unfortunately somewhat irreconcilable. Coal is such a compound substance, that two portions of a large lump may contain varying proportions of mineral matter, hydrogen, carbon, &c., and there is some difficulty attached to the procuring of an average sample from one part only of a given mass. From the experiments of Fleck, it would appear that coal deteriorates very considerably by being exposed to the atmosphere [illegible]th of time, and he gives the results of analyses of six samples of Saxon coals which had been exposed to the atmosphere for a period of nine years, and contrasts these with the analyses of the coals in their fresh condition.

As before observed, there is, very frequently, appreciable difference in the ash and chemical composition of even the same lump of coal, and the results obtained by Fleck tend certainly to strengthen this fact. That coal does deteriorate by long exposure is a fact which cannot be denied, but that they do not suffer to such an extent as is generally supposed, is probable. During a recent Board of Trade inquiry into the cause of an explosion of gas on board a steamer at Penarth, it was asserted that steam coal lost about 25 per cent. of its weight through oxidation or other cause by being conveyed to China. That the coal may shrink in bulk by attrition, accelerated by the motion of the vessel, can be easily credited, but it is needless to comment upon such an alleged loss by oxidation.

One point appears to be overlooked by nearly all those who have made experiments on the action of the atmosphere upon coal, and that is the enclosed gas which coals contain, and the fact that without exception carbonic acid in the gaseous condition is present in all. 'Varrentrap has long since shown that if a current of air be passed over coal, carbonic acid is formed at the ordinary temperature of the atmosphere,' but the question may be asked, how much of this carbonic acid existed already formed in the coal, and was gradually displaced therefrom simply by the diffusion of air into it? Until this question is answered satisfactorily, much importance cannot be attached to the finding of carbonic acid when oxygen or air is passed over coal. Some of the admirable experiments of Richter are open to the same objection. He found 'That when lignite was left exposed to air in a tube over mercury, oxygen was absorbed and carbonic acid produced.' Now lignites contain very appreciable quantities of carbonic acid, so that by simple displacement carbonic acid may find its way out of the coal, and atmospheric air or oxygen take its place. It must be admitted, however, that lignite does not oxidise readily, and as a consequence deteriorates quickly when exposed to the air. Oxidation in these coals is assisted by their losing water, and by their crumbling to fragments or splitting in every direction in consequence. Coals of the carboniferous formation are not so oxidisable as lignite, in fact they do not bear the slightest ratio to it. The author has been for some time engaged with experiments, which it is hoped will afford some further information. When coal is heated above the ordinary temperature of the atmosphere, its oxidability is greatly increased; this is so, according to Richter, with carboniferous coals as well as with lignite. The reason why lignite is more liable to oxidation than coals of the carboniferous formation may be due to the fact, as elicited in the investigation by the author, that lignite contains oily matters which may be susceptible of undergoing oxidation readily, and that decomposition has not advanced sufficiently far to convert the lignites into the more stable carboniferous coals. There are, however, some coals of the carboniferous formation, such [illegible] of South Staffordshire, which are ve[illegible]nd in the state of fine dust, are liable to undergo spontaneous combustion. Caking coals are of a bituminous nature, and the agglomerating property (caking) which they acquire by heating, appears to be, in some measure, due to the highly hydrogenised matter which they contain. These hydrogen compounds, through oxidation and partial evaporation, probably escape more rapidly than the general bulk of the coal; and on this account it is, perhaps, that some of the bituminous coals lose their caking properties after being exposed to air for some time. On the other hand, some highly bituminous coals do not possess the property of caking even when fresh obtained. The caking property may, therefore, depend more upon the state of combination in which the hydrogen is held than upon the actual quantity of bituminous or volatile matter present.

Deterioration of, or action of the weather upon, coal, is not more energetic, as a rule, upon bituminous than other carboniferous coals. The Scotch cannels, although of a very bituminous character, do not oxidise more readily than the more anthracitic. Indeed, cannel and jet are very stable bodies, resisting oxidation very effectively. If, however, much pyrites is present in coal, oxidation of the sulphide of iron will take place more rapidly, and, if in quantity, the oxidation of the pyrites will have the effect of bursting asunder the body of the coal, owing to the increase in bulk which the sulphide of iron acquires by being converted partially into ferrous sulphate or copperas, as green vitriol is commonly termed. The oxidation of pyrites is much assisted by heat and moisture, without which pyrites is more or less permanent. When coal, containing much combined sulphur, or in fact often with very little (for sulphur in the form of pyrites is not indispensable in order to start or support oxidation), is stacked in large masses, the temperature of the interior rises, and oxidation proceeds rapidly. This has been observed to take place with cannel coal when stacked up in stock at gasworks.

CHAPTER III.

PROPERTIES OF MATTER—EXPANSION AND CONTRACTION—ATOMIC VOLUME OF GASES—ATOMIC WEIGHT OF GASES—TABLE OF THE ELEMENTS AND CHEMICAL NOTATION—DIFFUSION OF GASES—TRANSPIRATION OF GASES.

THE term 'matter' includes the whole of the solid, liquid, and gaseous elements which constitute this planet, whether found on or above or beneath the surface of the earth.

Liquids may be regarded as occupying a position intermediate with solids and gases. These three states of matter are influenced in a great degree by heat, pressure, and cohesion. All matter may be regarded as consisting of atoms of indefinite size and weight, extended or expanded, according to the force which is brought to bear upon them. These atoms may be arranged into particles held together by virtue of cohesive force, and aggregated they form, for instance, metals, rocks, and solid substances generally. The particles of a liquid are also held together by cohesive force, but these are capable of moving freely upon one another, the cohesive force being weakened in this case by heat. The particles of a gas exhibit the weakest form of cohesive attraction.

According to the action of cohesive force, the particles of a metal, or other solid substance, lie in proximity to one another, and according to the extent to which cohesive force acts, so is its hardness regulated. Thus, for instance, the strain which the 'top rock' will bear when forming a roof across a ten-foot gallery depends entirely upon the cohesion of its particles. The closer the particles are arranged together, the greater will be the crushing power required to crack or rend the rock asunder. If a rod of zinc be bent and re-bent, its crystalline particles may be heard to grate against one another, the particles being placed, as it were, some distance apart. A substance or solid may be extremely hard and yet be incapable of bearing great tensile strain, or of being bent without fracturing. This is especially the case with metals or substances which have a peculiarly crystalline structure, and are constituted of atoms arranged in crystalline masses, which allow the free play of their faces upon each other. In addition to the properties of hardness and the capabilities of strain-bearing which the metals possess, some of them admit of being drawn out or lengthened without severing asunder the particles of which they are composed. This property is termed *ductility*. Iron, copper, and gold, for instance, may be drawn into very fine wire, and be still capable of bearing considerable strain, or dead weight, without breaking. The steel wire ropes, used for winding purposes in collieries, may be cited as examples of the strain-bearing properties of iron when drawn into fine wire, for steel is but a slight modification of iron, the only difference, in a chemical point of view, being that it contains a trifle more carbon than iron (malleable). It would not, however, be possible to make a steel-wire rope without first bringing the metal into a condition approaching a white heat, and here the part which heat plays in altering the cohesive force of matter can be clearly seen. By the aid of heat the steel is first brought into an entirely different state before it is drawn into wire; in fact, into a pasty form, or a state bordering upon its being converted from a solid to a liquid.

The liquid and gaseous states of matter, especially the latter, are those which more especially claim our attention. In liquid matter there is sufficient cohesion of particles to enable them to hold together, and also for one group of particles to exert some affinity for another group. A globule of water will, on touching another globule, unite with it and form a larger one. This is exemplified more strikingly if other affinities or attractions which a liquid may have for a solid, are absent or overcome; such in fact as when water is poured upon a surface smeared with oil or grease. The repulsion of the liquid particles by the fat causes them to run into each other with greater facility. On the other hand, if benzole or ether be poured upon a fatty surface the liquid globules would not have the same tendency to run together as was the case with water, owing to the solvent power of the ether on the fat. The force of cohesion is strengthened or weakened by various surrounding influences. The effect of pressure upon liquid matter is very inconsiderable, but by the aid of heat a liquid is readily converted into a gas or vapour, and its cohesive force is greatly weakened. By the application of cold, however, the cohesive force of liquids is increased, and if sufficient cold be brought to bear upon the liquid, a solid will result—at least this is true in nearly all instances; and those liquids which have not yet been frozen or converted into solids would doubtless undergo this change, could we but obtain a temperature low enough for the purpose. The cohesive force brought about by cold is strikingly shown in the case of water, which disintegrates rocks and other material through the slight increase of bulk which results during its passage from the liquid to the solid condition. Heat causes all liquids to expand in bulk, and consequently lessens the cohesive force of their particles. By the action of heat a liquid may be converted into vapour; in fact, a solid may first assume the liquid condition and ultimately pass into the state of vapour; therefore, upon the application of cold, a vapour may be transformed into a solid, as may be the case with water, for instance. Gases may, in like manner, be condensed into liquids by extreme cold. A solid or liquid is little influenced by pressure without the disintegration of the former or the application of cold to the latter. Gaseous matter is influenced by pressure in a high degree, without, however, adding permanently to the cohesive force of its particles, but only for such a time as the actual pressure is applied. By the application of pressure the particles of a gas are brought closer together, and their freedom of mobility lessened according to the pressure employed; but as soon as that force is removed, they return again to their original condition. The atoms of a gas are held together by virtue of special affinities, such as the attraction of the earth upon the atmosphere, the force of cohesion being but weakly exerted.

When gases are rarefied or have their density lessened by decreased barometric pressure, the particles are further removed from one another, and the gas expands; the application of heat effects a like result. The action of wind on, or the motion of air-currents in, the atmosphere, augments the force of cohesion; that is, it brings the particles of air closer together, because the compressed portion meets with a resistance as it encounters fresh air moving at a lesser velocity. The force of cohesion brought about by pressure on the particles of air in the ventilating current of a mine would be greatest at the bottom of the downcast shaft. In the upcast shaft it is the effect of heat in expanding, and thus lessening, the density of the air by forcing the particles asunder, which generates the velocity of the ascending, or ventilating, current, when furnace action is employed. In any case the heat of the mine, and that due to the breathing of men and animals, and the combustion of oil in lamps, will have the effect of assisting the ventilating current by driving the particles of air asunder; and, in doing this, the particles of air so separated would encounter more resistance from the intake or heavier particles of air, than from the particles which had already become heated, and a current of air travelling in the direction of the upcast shaft would result.

We have hitherto noticed matter only as a whole, recognising three different states or conditions—liquid, solid, and gaseous. Matter in each of these conditions may be divided into two kinds, 'simple matter,' and 'compound matter.' Simple matter, or a simple substance, is one which is incapable of being resolved by any known means into two or more portions, which shall possess properties differing from one another. The simple substances are termed *elements*, and the elements are the primary constituents from which all other matter, either gaseous, liquid, or solid, is formed. Compound matter, or a compound substance, is one which is capable of being divided into two or more substances which possess different properties. As an instance of simple solid matter, the metal iron (in its pure condition) may be taken, and of compound matter, almost any solid met with in nature—coal, rock, &c. The metal, mercury, may be cited as an instance of liquid simple matter, and water, or almost every other liquid, as compound matter:—very few of the elements being liquid, at the ordinary temperature of the atmosphere. Simple gaseous matter embraces three of the gases, which will be described in future pages, viz., oxygen, nitrogen, and hydrogen; and compound gaseous matter includes all the other gases, as marsh-gas, sulphuretted hydrogen, &c.

Expansion and Contraction.—Gases increase in volume when the temperature is raised, as previously observed. This increase in bulk is not accidental or variable, but always conforms to a given law. All the gases with which we shall have to deal in this treatise, expand for every extra degree of temperature above 0° on Fahrenheit's scale 1-459 part of their volume, or 1-273 part of their volume for every extra degree of temperature on the Centigrade scale. Decreased barometric pressure exerts the same influence upon atmospheric air as heat does. The lowering of the barometer 1-16 of an inch would have about the same expansive effect on the atmosphere as raising the temperature 1° F. Cold and pressure, on the other hand, cause a gas to occupy less space, or to contract in bulk. The property which gases possess of having their particles brought into closer space, or of receding from each other, according to the force which is brought to bear, confers upon them the power of elasticity, inasmuch as they can be condensed into a much smaller volume by the application of pressure, or can be rarefied or expanded when pressure is removed. It was observed by Boyle, in 1661, that gases expand or contract under reduced or increased pressure always in the same proportion, and from this the following law has been deduced: '*The volume of a gas varies inversely as the pressure upon it, and the density and elastic force are directly as the pressure and inversely as the volume.*'

All permanent gases conform to the above law, but those which are condensable and can be liquefied under the effect of pressure and cold, shrink in volume more than this law indicates, especially when the point of liquefaction is nearly attained. The permanent gases are oxygen, nitrogen, hydrogen, carbonic oxide, nitric oxide and marsh-gas.[1] Carbonic acid and all other gases can be condensed and liquefied, when subjected to pressure, at very low temperatures. The force with which a gas resists compression is termed its *tension*, and its maximum tension is, naturally, the point of liquefaction. If a given volume of gas is subjected to a pressure of 60 inches of mercury, or 2 atmospheres, it will be reduced to one-half of its original volume. If a pressure equal to 3 atmospheres, or 90 inches of mercury, be exerted, the gas will occupy only one-third of its original volume, but as soon as the extra pressure is removed the gas will immediately fill the space of the volume employed, provided the precaution is taken of keeping the temperature uniform, or after allowing for any increase or decrease of temperature. If the temperature of a gas, placed in a closed glass globe under ordinary atmospheric pressure, be raised from 0° F. to 459° F., the pressure of the gas inside the glass globe will be the same as if it were under the compressing influence of 60 inches of mercury, or 2 atmospheres, because a given volume of gas would become doubled by raising the temperature 459° F., provided the original temperature of the gas was 0° F. In the same manner, by the lowering of the temperature from 459° F to 0° F, if the experiment be performed with the gas in a sealed tube, the gas will contract in bulk, so as to admit of two volumes occupying the place of one, without pressing against the inside of the tube with greater force than the atmosphere from without.

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[1] M. Pictet and M. Cailletet have accomplished the liquefaction of all the six previously termed permanent gases.

Atomic volume of gases.—All simple gases or elements are supposed to be constituted of an equal number of atoms which are of the same size, and, consequently, the simple gases occupy equal volumes, the difference in weight of the respective gases being due to the difference in weight of the atoms of which they are composed. If, therefore, we make experimentally some pure oxygen and some pure nitrogen gas, and 4 parts of the latter gas is mixed with 1 part (by volume) of the former, they will occupy the same volume when mixed together as 5 such parts of air. Compound gases, as a rule, occupy two volumes when compared with hydrogen or any other simple gas; in fact all the compound gases which will be noticed in this treatise occupy two volumes. This difference between simple and compound gases is explained by the fact that the combined atoms of a compound gas are twice as large as an atom of hydrogen. What is meant by a compound gas is, not a mixture of simple gases, but two simple gases chemically combined. If it were possible for carbon to exist in the form of gas and *mixed* with an equal volume of oxygen, and these two gases were to combine and form carbonic oxide, the latter compound gas would occupy exactly the same space as the free gases previous to their union. We have to deal with gases of a much more complex character than carbonic oxide, such as marsh-gas (fire-damp), carbonic acid, hydride of ethyl, sulphuretted hydrogen, &c. Marsh-gas is composed of 4 atoms or parts of hydrogen united with 1 atom or part of carbon, in all 5 atoms or parts which occupy 5 separate volumes in the free state. When these 5 atoms combine to form mash-gas, they close together to such an extent as to occupy the space of 2 atoms of hydrogen, or, in other words, the 5 atoms which constitute marsh-gas, at the moment of combination, shrink into 2-5ths of their original volume. Carbonic acid consists of 1 atom of carbon and 2 atoms of oxygen, in all 3 volumes or atoms, which in the state of combination are confined in the space of 2 atoms of hydrogen. Hydride of ethyl (C_2H_6) consists of 2 atoms of carbon and 6 atoms of hydrogen, in all 8 separate atoms, which in the act of combining together shrink into the space occupied by 2 atoms of hydrogen.

Atomic weight of gases.—We have already noticed that all equal volumes of simple gases are supposed to contain an equal number of atoms which are of the same size. The weight of the atoms of gases differs according to their specific gravities. Dalton found, on examining marsh-gas CH_4, and olefiant gas C_2H_4, that the ratio of the hydrogen to the carbon in the former, was twice as great as in the latter gas; this he deduced from the chemical composition of the gases by weight, the ratio of the carbon to the hydrogen being in the case of marsh-gas as 6 is to 2, and in the case of olefiant gas as 6 is to 1. He also noticed that there was a certain constant ratio, between compounds of carbon with oxygen, and, by pushing his investigation further, he found that chemical compounds are not only formed of definite proportions of the elements of which they are composed, but that when one element combines in two different proportions with another element, those proportions are always multiples of one another: establishing the '*law of combination in definite and multiple proportions.*' There is twice as much oxygen in carbonic acid as there is in carbonic oxide, the ratio by weight being as 6 of carbon to 16 of oxygen in carbonic acid, and 6 of carbon to 8 of oxygen in carbonic oxide.

Hydrogen, which is the lightest body known, has been taken as the unit or [illegible] atomic weight, and is represented by 1. As, volume for volume, oxygen is 16 times heavier than hydrogen, and the atomic weight of hydrogen is 1, then that of oxygen must be 16. Volume for volume, nitrogen is 14 times heavier than hydrogen, therefore its atomic weight is 14. The table, page 75, shows the atomic weight of all the known elements which constitute the infinite number of substances of which terrestrial matter is composed.

If a number of simple gases are mixed together, the weight of a given quantity of the mixture will be found by multiplying the density of each gas by its percentage volume, and then adding the results. A mixture of equal volumes of hydrogen and oxygen which measure one cubic foot, will weigh (oxygen $\frac{16}{2}$ + $\frac{1}{2}$ hydrogen = $8\frac{1}{2}$), as much as $8\frac{1}{2}$ cubic feet of hydrogen.

As previously noticed, all compound gases met with in coal mines occupy two *volumes* when compared with hydrogen; it follows, therefore, that the *weight* of any of them, compared with hydrogen, will be one-half the sum of the atomic weights of the gases of which they are composed, thus:—Carbonic acid, CO_2, consists of one atom of carbon combined with two atoms of oxygen, $C=12$ and $O=16$, then $12+(16\times2)=44$, and half of 44 is 22, which is the weight of carbonic acid compared with hydrogen, volume for volume. Marsh-gas, CH_4, contains one atom of carbon and four atoms of hydrogen, then $12+4=16$, and 16 divided by 2 is 8, therefore marsh-gas is 8 times heavier than hydrogen. The weight of air compared with hydrogen is 14·4. Air, however, is taken as the standard of specific gravity of gases, and is consequently represented by unity

(1·0000). The specific gravity of marsh-gas, as determined by experiment, is ·5576, taking air as 1·0000. The specific gravity of a gas may be calculated from the atomic weights; thus in the case of marsh-gas, compared with air, the ratio of their weights is as 14·4 air and 8 marsh-gas, then 8 divided by 14·4=·5555, which is practically that obtained by experiment. The specific gravity of the other gases is given under the head of each.

Chemical Notation.—In order to shorten as much as possible the writing of chemical compounds, so as to demonstrate their union and decomposition by equations, the *elements* are represented by symbols, which are either simply the capital letter of the name of the element, or, in case several elements commence with the same letter, the following, or other letter of the word in small type, is added. For instance, chlorine, cobalt, and carbon begin with the same letter, and are represented symbolically by Cl, Co, C. The non-metallic elements are given the preference; accordingly oxygen, nitrogen, carbon, and sulphur are represented by O, N, C, S. A few of the elements take their symbols from their Latin names, as gold, iron, mercury, &c.

In denoting the symbols of compounds, those of the elements of which they are composed are merely brought together; thus, carbonic oxide is simply written CO. When two or more atoms of one element are united with another, a small number expressing the atoms so united is placed after the symbol of the element:—

Carbonic Acid, CO_2. Marsh-gas, CH_4.

Name	Symbol	Atomic Weight	Name	Symbol	Atomic Weight
Aluminium	Al	27·5	Mercury	Hg	200·0
Antimony	Sb	122·0	Molybdenum	Mo	92·0
Arsenic	As	75·0	Nickel	Ni	58·8
Barium	Ba	137·0	Niobium	Nb	97·6
Beryllium	Be	9·3	Nitrogen	N	14·0
Bismuth	Bi	208·0	Osmium	Os	199·0
Boron	B	11·0	Oxygen	O	16·0
Bromine	Br	80·0	Palladium	Pd	106·5
Cadmium	Cd	112·0	Phosphorus	P	31·0
Cæsium	Cs	133·0	Platinum	Pt	197·4
Calcium	Ca	40·0	Potassium	K	39·0
Carbon	C	12·0	Rhodium	Rh	104·0
Cerium	Ce	92·0	Rubidium	Rb	85·5
Chlorine	Cl	35·5	Ruthenium	Ru	104·0
Chromium	Cr	52·5	Selenium	S	79·0
Cobalt	Co	58·8	Silicon	Si	28·5
Copper	Cu	63·5	Silver	Ag	108·0
Davyum	Da	154 ?	Sodium	Na	23·0
Didymium	D	96·0	Strontium	Sr	87·5
Fluorine	F	19·0	Sulphur	S	32·0
Gallium	Ga	69·9 ?	Tantalum	Ta	137·5
Glucinum	G	14·0	Tellurium	Te	128·0
Gold	Au	196·7	Thallium	Tl	204·0
Hydrogen	H	1·0	Thorium	Th	231·5
Indium	In	74·0	Tin	Sn	118·0
Iodine	I	127·0	Titanium	Ti	50·0
Iridium	Ir	198·0	Tungsten	W	184·0
Iron	Fe	56·0	Uranium	U	120·0
Lanthanum	L	92·0	Vanadium	V	51·2
Lead	Pb	207·0	Yttrium	Y	68·0
Lithium	Li	7·0	Zinc	Zn	65·0
Magnesium	Mg	24·0	Zirconium	Zr	90·0
Manganese	Mn	55·0			

Diffusion of Gases.—Of all the laws which influence gaseous matter, the *law of diffusion* is one which has more connection with mining, or rather with the gases met with in coal mines, than perhaps any other; and it is essentially necessary that this law should be thoroughly understood, in order to comprehend the various phenomena of the gases known as fire-damp, and of atmospheric air in connection with the ventilation of a colliery. Gases differ considerably in specific gravity—oxygen is 16 times as heavy as hydrogen, marsh-gas is 8 times as heavy as hydrogen, carbonic acid 22 times, and sulphurous acid 32 times as heavy as hydrogen. If a mixture of water, oil, and sand be shaken up together, the particles intermix as long as agitation proceeds; but if the vessel containing them be set at rest for a moment, they will be found arranged in layers according to their respective densities, or in the same manner as they were before agitation. It would be only natural to suppose that the gases we have mentioned would conform to the same rule in a gallery or heading in a mine, and indeed in practice we find that to a certain extent they *apparently* do; the reason of this will be shown further on. If such were the case, however, the earth would be covered with a stratum of carbonic acid which would, by force of gravity, find its way into every pit and mine, and so render it impossible to work them. The law of diffusion so regulates this, that whatever may be the weight of a gas, it will mix or diffuse through a lighter one in every direction, up, down, or sideways, quite independently of any force or current. If, for instance, two soda-water bottles be connected together by a glass, tin, iron, or any other tube, passing through a tightly-fitting cork in each bottle, and one of the bottles be previously filled with hydrogen, and the other with oxygen, and allowed to remain at rest, so that the bottle containing the hydrogen shall be uppermost, the lighter gas, hydrogen, will descend into the oxygen bottle, and the heavier gas, oxygen, will ascend into the hydrogen bottle. After the lapse of two or three hours, to prove the experiment, the oxygen bottle may be detached, covered lightly with a cloth, to prevent injury to the hand in case the bottle be fractured, and a light applied to the mouth, when a smart explosion will take place, showing that the hydrogen must have diffused downwards into the oxygen, and the oxygen upwards into the hydrogen. The other bottle will, of course, afford a like result. Or the two bottles, previous to being arranged in a similar manner, may be filled, the top one with hydrogen and the bottom one with carbonic acid (22 times as heavy), and after standing some time detach the top bottle, and determine the presence of carbonic acid therein by adding a little lime-water. The soda-water bottles may be filled with gas by displacement over warm water; for method of preparation see respective gases.

Graham found that when a cylinder, fitted with a movable tube bent at right angles, was placed in a horizontal position, and the mouth of the bent tube turned upwards when the gas operated on was heavier than air, and downward when the gas was lighter than air, the gas introduced into the cylinder escaped, and in a greater or lesser period, according to the nature of the gas, the cylinder was entirely occupied with atmospheric air. He observed that hydrogen escaped more quickly than marsh-gas, and marsh-gas more quickly than carbonic acid, and from the results of his experiments he deduced the law that 'gases diffuse through or mix with one another *inversely as the square root of their densities.*'

The following table, from 'Watts' Dictionary of

Chemistry,' exhibits the densities of several gases; the square root of the density, or the calculated ratio of the times required for the diffusion of equal volumes, that of air being assumed to be equal to 1; the reciprocal of the square root or the calculated diffusiveness of the gas, and lastly the rates of diffusion as determined by experiment—the barometric pressure and temperature being taken as the same for all gases.

Gas	Density	Square Root of Density	$\frac{1}{\sqrt{\text{Density}}}$	Velocity of Diffusion Air = 1
Hydrogen . .	0·06926	0·2632	3·7794	3·83
Marsh-gas . .	0·559	0·559	1·3375	1·344
Steam . . .	0·6235	0·7896	1·2664	—
Carbonic oxide .	0·9678	0·9837	1·0165	1·0149
Nitrogen . . .	0·9713	0·9856	1·0147	1·0143
Ethylene . . .	0·978	0·9889	1·0112	1·0191
Nitric oxide . .	1·039	1·0196	0·9808	—
Oxygen . . .	1·1056	1·0515	0·9510	0·9487
Sulphydric acid .	1·1912	1·0914	0·9162	0·95
Nitrous oxide . .	1·527	1·2357	0·8092	0·82
Carbonic acid . .	1·52901	1·2365	0·8087	0·812
Sulphurous acid .	2·247	1·4991	0·6671	0·68

We have already noticed that heavy gases will diffuse and mix through lighter ones, and light gases will diffuse and mix through heavy ones, but the lighter the gas is the more rapidly will it diffuse. The same quantity of air travelling through a mine at the same rate or velocity would diffuse or mix with a much larger volume of hydrogen or marsh-gas than it would of carbonic acid, because the square root of the density of carbonic acid is greater than either that of hydrogen or marsh-gas. By square root is meant that number which multiplied by itself will give the number corresponding to the density of the gas; thus from the table we find that the square root of the density of hydrogen is ·2632, and this number multiplied by itself will give the density of that gas. In the last column of the table the velocity of diffusion of gases is given compared with air as unity, and from this it will be seen that 1344 volumes of marsh-gas will diffuse in the same time as 1,000 volumes of air or 812 volumes of carbonic acid. It will be seen, therefore, that the same quantity of air travelling through a mine would carry off by diffusion more than 1½ times as much marsh-gas as carbonic acid.

In order to show the different rates of velocity of diffusion of different gases, take a glass tube about 12 inches long and 1 inch in diameter, and close one end of the tube with a plug of dry plaster of Paris. This is accomplished by introducing into the glass tube a rod of wood which is of the same diameter, and which occupies the whole length of the tube, with the exception of about a quarter of an inch. Plaster of Paris, mixed with water into a pasty condition, is carefully pressed until it completely fills the quarter of an inch unoccupied by the rod of wood, and left to stand until it has become set and dry. Gases pass readily through this layer of plaster of Paris, when it is dry, but it is impervious to gas when wet; care is necessary, therefore, in order to avoid wetting the plaster plug in the act of filling the tube with any gas, for the purpose of observing its diffusive rate. To remove the air from the tube so as to fill it with gas when mercury is not at hand, the open end of the tube is placed in a vessel of water, and a small indiarubber or bent glass tube is inserted to within half an inch of the plaster plug. The air is withdrawn by applying suction with the mouth, until the glass tube is filled with water within half an inch from the plaster.

The quantity of air left in the tube is marked by a small bit of gummed paper, and when the tube is nearly filled with hydrogen or any other gas used for the experiment (but which must of course be lighter than air), another bit of gummed paper may be placed on the tube at the level of the water in it. Before filling the tube with water it is advisable to tie a piece of thin sheet indiarubber or bladder moistened on the outside, around the end of the tube containing the plaster plug, because if it is subsequently filled with hydrogen without this precaution being taken, the gas will escape with great rapidity.

If the tube (standing in a dish of water) has been filled with hydrogen, which is the best gas to use on account of its lightness, as soon as the covering is removed, the water will quickly rise in the tube, and after a short time the residual gas will consist entirely of air, and will occupy about one-fourth of the hydrogen added, after deducting the air left in the glass tube in the first instance. By the aid of such a tube, closed on one end by a thin sheet of artificial graphite, Graham determined the rate of diffusion of the different gases, and deduced the law before mentioned.

The author has met with intelligent colliery officers who have asserted that what is meant by the diffusion of gases is the exertion of [illegible] caused by the wind, or the app[illegible] power as that supplied by fan or furnace action in a mine, and that gases removed or apart from such force remain in perfect rest. This is a very erroneous idea of the law of diffusion, as all gases are in constant motion, even after complete mixture has taken place; at the same time, the rate of diffusion is in ratio to the velocity or travelling rate of the gases. Gases are never at rest, the particles or atoms of which they are composed continually travel in all directions: this is termed '*mutual diffusion.*' The mutual diffusive force would, however, be very insufficient to keep a mine in a condition fit for men and animals to work in, and consequently artificial means are employed to assist the diffusion and removal of fire-damp, and the carbonic acid generated by respiration, by inducing powerful currents of air to traverse the mine. The atmosphere drawn into a mine by these induced currents maintains its usual composition, and the difference in density of the two gases, oxygen and nitrogen, makes no alteration in their respective volumes.

The power of diffusion possessed by gas is surprisingly strong, as will be proved by the following experiment:—A wide-mouthed bottle is filled with hydrogen gas in the manner previously described, and a thin sheet of caoutchouc is very tightly tied over the mouth of the bottle (the very thin indiarubber toy balloons will suit very well). The hydrogen will escape from the bottle through the substance of the indiarubber much quicker than air will pass inwards to supply its place, and, regardless of the pressure of the atmosphere on the indiarubber sheet, diffusion will proceed, until after a longer or shorter time, according to the freedom of the bottle and its covering from water, the indiarubber sheet will be forced inwards by the pressure of the atmosphere to such an extent as to finally cause it to burst.

Transpiration of Gases.—The influence which this law bears upon the gases which find their way into coal mines from seams of coal, is, probably, one of no small importance. It has ever been recognised that the gases known as fire-damp escape more readily from coal under the influence of low barometric pressure, and the reason of the inpour of explosive gases is generally explained by the lesser resistance of the atmosphere upon the working face of coal and other exposed material. The law of diffusion bearing upon the gases which escape from coal has also long been recognised; that is to say, when the gases evolved from coal have found their way into goaves, or into the galleries of coal mines, they are known to mix with air by diffusion, so as to form an explosive mixture, or become so diluted by the ventilating current as to be removed from the mine without doing any harm.

We are not aware, however, that the influence of *the law of the capillary transpiration of gases* has ever been brought forward to account for the increased inpour of fire-damp under barometric depression, or that this law has ever been described in connection with the gases met with in coal mines. The influence of the law of diffusion ceases most probably when the working face of the coal is reached, or, at any rate, diffusion of atmospheric air would not proceed into the working face to a greater depth than one inch, provided the coal was not of a very porous character. The gases enclosed in the coal make their exit at the working face, but there is no telling from what distance they are slowly making their way thereto. Then again, the gases in coal are present under immense pressure, and do not make their way out of it simply by diffusive force; in fact, under these conditions, diffusion may be said to have little or nothing to do with the quantity of gas evolved.

Graham[1] found that when gases passed through a capillary tube of very minute aperture, and whose length was 4,000 times its diameter, the ratio of flow of different gases bore a constant ratio to each other, but the rates of velocity were not in accordance with the velocity of diffusion of gases. The following table, from 'Watts' Dictionary of Chemistry,' shows the rates of transpirability of different gases :—

Gases	Times for transpiration of equal volumes	Velocities of transpiration
Oxygen	1·0000	1·0000
Air	0·9030	1·1074
Nitrogen	0·8768	1·141
Nitric Oxide	0·8764	1·141
Carbonic Oxide	0·8737	1·145
Nitrous Oxide	0·7493	1·335
Hydrochloric Acid	0·7363	1·358
Carbonic Acid	0·7300	1·370
Chlorine	0·6664	1·500
Sulphurous Acid	0·6500	1·538
Sulphydric Acid	0·6195	1·614
Marsh-gas	0·5510	1·815
Ammonia	0·5115	1·955
Cyanogen	0·5060	1·976
Ethylene	0·5051	1·980
Hydrogen	0·4370	2·288

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[1] *Elements of Chemistry*, 2nd edition, vol. i. p. 82.

Now it is evident that since the gases in coal are distributed throughout its mass, and that true coal is, as a rule, close-grained, the gases must be enclosed or imprisoned in pores or interstices of very great minuteness. This will become more apparent when a small portion of coal is viewed under the microscope.

When the enclosed gas is in the act of escaping from the working face of coal, the immense pressure under which it is stored forces it to traverse these minute pores or interstices, and accordingly the gases are made to pass, or are transpired through, as it were, a fine capillary tube of great length; and the enclosed gases will most probably escape in accordance with their respective rates of capillary transpiration.

In Graham's experiments, from which the transpiration velocities are deduced, the gas used was made to pass through the capillary tube which he employed by connecting one end of the same with a receiver standing on the plate of an air-pump, the gas being forced through the capillary tube by the pressure of the atmosphere when a partial vacuum was formed by the air-pump. It is true that these conditions are not very similar to those under which the gases are made to transpire through coal, but in either case it is transpiration. The gases in coal are forced into the atmosphere (air current) by a pressure infinitely greater than that which they have to encounter: this too was the case in Graham's experiments. He found that there was one very curious circumstance connected with the law of transpiration of gases, viz.—the effect of *density* upon the transpiration rate; the more dense air is, the more rapidly will a given volume of it be transpired. In other words, Graham found that if the density of air was doubled, it would, by the application of an equal force, be transpired in *half* the time of air of the ordinary density, and he remarks, 'Nor can the phenomenon of transpiration be an effect of friction, for the greater the density of air, the more should its passage be resisted by friction; and hence the transpiration of air and *all* gases is greatly affected by variations of the barometer.'

In coal, the density of the enclosed gases will depend upon the pressure under which they are imprisoned, and not upon any variation of the barometer; say, for instance, that the gases were present in coal under a pressure of 300 lbs. to the square inch, then this 300 lbs. pressure would be spent in transpiring the gases into a space occupied by gases (air current) under a pressure of 14·7 lbs. upon the square inch, or, in other words, the 300 lbs. pressure would be spent in transpiring the gases in the coal into the air current, which, taking the barometer at 30 in., would be under a pressure of 14·7 lbs. to the square inch. The ratio of the transpiration pressure to the pressure of the air current would be as 20·4 is to 1. If the barometer lowers one inch, the ratio of the above pressure will be as 21·1 is to 1, while the density of the enclosed gas will be the same. It is probable, therefore, if the barometer lowers one inch, and by so doing removes naturally 1-30th of the opposing pressure of the air, the rate of transpiration will increase 2-30ths, or 1-15th more gas will be evolved. This effect of capillary transpiration, as in the case of coal, might be verified by experiment. If the increase in the velocity of transpiration be proportional to the times of difference of pressure between the propulsive force and that which it ultimately encounters, then the increase of gas evolved would be 20-30ths, or ⅔ more.

CHAPTER IV.

OXYGEN—NITROGEN—ATMOSPHERIC AIR—THE ATMOSPHERE.

Oxygen.

Symbol O. Atomic weight 16.

1 litre weighs at 32° F. and bar. 30 in. . . 1·434 gram.
1,000 cubic feet weigh at 32° F. and bar. 30 in. . 89·342 lbs.

OXYGEN gas is sixteen times heavier than hydrogen, which is taken as the unit of standard of all simple bodies, or elements, as they are termed. Oxygen was discovered by Priestley in 1774. It is the most widely diffused of all the elements, and constitutes nearly one-half of our globe, and eight-ninths of water by weight. It is, for the most part, in combination with other elements that it forms so large a portion of our planet; in its gaseous condition as it exists in the atmosphere the quantity is comparatively small. It has neither taste, odour, nor colour, and is one of the permanent gases; that is to say, it has only recently been liquefied by the aid of the strongest pressure and lowest temperature obtainable. (See p. 69.) Oxygen sustains animal life, and ordinary combustion cannot proceed without its presence. Fish life is also dependent upon the oxygen dissolved in water. It is soluble to the extent of about 3 parts by volume in 100 parts of water. If, therefore, water contains much organic matter undergoing decomposition, this free or dissolved oxygen is required to oxidise it. We have already noticed that in the case of stagnant pools containing decomposing plant material, fish could not live in them but for the purifying influence of the oxygen.

Bodies which ignite in air burn with increased brilliancy in pure oxygen, and combustion proceeds much more rapidly and with greater splendour than in air. Charcoal or wood, sulphur, and phosphorus burn very vividly, the former throwing off scintillations in all directions. Potassium, sodium, magnesium, and iron in the form of fine wire, give a very fine effect when burnt in oxygen. Oxygen is not prepared from atmospheric air for the purpose of experiment, but from a salt known as chlorate of potash, which contains about 40 per cent., the whole of which can be driven off and collected by the application of heat. An iron or copper retort, or a glass flask—a Florence oil-flask answers well—provided with a tightly-fitting perforated cork and bent tube, is partly filled with a mixture of three or four parts of chlorate of potash and one part of black oxide of manganese,[1] and heat applied, when oxygen gas will be given off readily, and may be collected in tubes previously filled with, and standing over, water. It can also be obtai [illegible] omposing water acidified with sulphur [illegible] aid of a galvanic battery, or by [illegible] uric oxide in a glass tube. When pure oxygen is required, it is made from pure chlorate of potash by introducing some of the powdered compound into a glass bulb previously blown on the end of a glass tube, and afterwards drawing out the neck and bending the glass tube so as to form a retort. The temperature required to drive off the oxygen is much greater when chlorate of potash is employed alone, than when it is mixed with oxide of manganese, although the manganese does not undergo any change in the process. Oxygen can also be prepared from oxide of manganese alone by heating it to a high temperature in an iron retort; but for all ordinary purposes of experiment it is made from chlorate of potash mixed with oxide of manganese, as first described. The gas may be collected in tubes over water.

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[1] Care [illegible] ntimony is not substituted by mista [illegible] ay result in consequence.

Combustion in pure oxygen and combustion in air amount to one and the same thing; for air consists of pure oxygen diluted with four times its volume of nitrogen (together with *small* quantities of other gases and vapours). The combustion or burning of carbon in the state of coal in oxygen or air, and the slow combustion or burning, so to speak, of the carbon of the food by the action of oxygen supplied to the lungs and blood, are analogous processes. If a piece of coal be ignited and introduced into pure oxygen, it will burn much more quickly than it would in air, evolving more heat and light, but it will be exhausted or consumed much sooner; still the actual heat produced is the same, and the products of combustion are the same in both cases. The temperature of the coal burning in oxygen may be much higher for the time; but if the degrees of heat produced were multiplied, in both instances, by the actual period of combustion, the amount of heat generated would be identical, and the products in either case are carbonic acid and water with more or less sulphuric acid, from the oxidation of sulphur present in the coal. In the same way the burning of carbon in our ordinary fires is, of course, some hundreds of degrees above that in which it is converted by slow combustion into carbonic acid in the animal economy; the products are, however, similar, the only difference being the temperature at which combustion proceeds. During the conversion of vegetable matter into coal, slow combustion or oxidation must have been going on for countless ages, and much carbonic acid and water were formed.

All substances which undergo combustion in oxygen or air are converted into what are termed oxides; thus carbonic oxide, CO, is an oxide of carbon; water, OH_2, is the oxide of hydrogen; sulphurous acid or dioxide, is an oxide of sulphur. Free oxygen, even at the ordinary temperature, acts with great energy upon some substances, and shows considerable chemical activity. Some organic substances, such as oiled waste, and hay stacked in a damp and green condition, finally undergo spontaneous combustion through slow oxidation. The presence of moisture appears to facilitate the action of oxygen at the ordinary temperature. Bright iron and lead become covered with oxide in the presence of moisture, whereas in dry air or oxygen no oxidation takes place.

Oxygen unites with all the elements excepting fluorine with the production of heat, and sometimes light. The nature of the resulting oxide depends upon the element from which it is produced, and the state of oxidation. Carbon, when completely burnt, yields the dioxide, or carbonic acid, as it is commonly termed, which is an acid oxide. Sulphur and phosphorus also yield acid oxides, while potassium, iron, magnesium, &c., give basic oxides. The acid oxides, in combination with water, form liquids which have generally a sour taste, and possess the property of changing the colour of vegetable blues to red. Basic oxides possess the property of combining with the acid oxides to form chemical compounds, which are generally characterised by their neutral properties; thus when oxide of calcium (basic oxide) combines with carbonic acid (acid oxide) carbonate of calcium or chalk results.

$$\underset{\text{Oxide of calcium, or lime.}}{CaO} + Co_2 = \underset{\text{Carbonate of lime, or carbonate of calcium.}}{CO_3Ca}$$

Some oxides, as water (oxide of hydrogen) and carbonic oxide have neutral properties; that is to say, they do not act upon or destroy vegetable colours, and are termed neutral oxides.

Oxygen is capable of existing in a peculiar condition, having its atoms arranged, apparently, in definite combination, and in this form it possesses properties differing very considerably from ordinary oxygen, both with regard to its chemical activity and general action. In the vicinity of an electrical machine the air has a powerful odour, and the same smell is perceived when a spark from a coil is passing between two wires, and is similar it appears to that which is sensible in the air during a thunderstorm.

This modification of oxygen is called ozone (from its strong odour), and consists of three atoms of oxygen condensed so as to occupy the space of two atoms of ordinary oxygen. It has a peculiar smell, and possesses very active properties. It is obtained by passing electric sparks through oxygen gas, or by placing phosphorus in a jar of oxygen, and is also supposed to be evolved by plants under the influence of sunlight, and to constitute Nature's disinfectant, as it is capable of exercising great power in destroying offensive odours and oxidising organic matters. Recent researches have shown that oxygen under increased pressure appears to act destructively by over-exciting, and animals do not live for any length of time in an atmosphere of much greater density than our own. Rarefied air also acts deleteriously by lessening the quantity of oxygen required. The fact that man and animals were born and live in an atmosphere the density of which does not alter to any considerable degree, may account for this action of rarefied or compressed air. The small difference in pressure which miners experience in a coal-mine over that on the surface is not sufficient, however, to materially influence them. It is when the pressure of the atmosphere is reduced several pounds, or increased several pounds, that the ill effects are experienced; but, provided the increase of pressure does not come on too suddenly, it can be borne for some time without much inconvenience.

Nitrogen.

Symbol N. Atomic weight 14.
1 litre of gas at 32° F. and bar. 30 in. weighs . . 1·254 gram.
1,000 cubic feet of gas at 32° F. and bar. 30 in. weigh 78·175 lbs.

The term nitrogen, which signifies the nitre producer, was applied to this gas because it forms in combination with oxygen and potash, nitre or saltpetre. It is also known, especially in France, as *azote*,—that part of the atmosphere which does not support life. Nitrogen is characterised by its negative qualities and general chemical indifference in the free state. It is destitute of colour, taste, or smell, and is incapable of supporting combustion or animal life, but is not poisonous, and causes death when breathed (unmixed with oxygen) only by excluding oxygen from the lungs. It was long incondensable at any temperature or under pressure,[1] but it has recently been condensed to the liquid form, and is somewhat lighter than air in the ratio of 972 to 1,000. Nitrogen may be said to be combustible under peculiar conditions, as by the aid of electric discharges, in contact with oxygen, it is slowly converted into nitric acid.

The negative qualities possessed by nitrogen render it very suitable as a diluent to be mixed with oxygen in the form of atmospheric air, in order to lessen and retard the oxidising action of oxygen, which would otherwise be uncontrollable. A very ready mode of preparing pure nitrogen gas is to decompose nitrite of potash by chloride of ammonia (sal ammoniac). When an aqueous solution of the two salts is boiled, pure nitrogen is evolved. When nitrogen gas is required for experiment, it is usually obtained from air by burning phosphorus in a small dish in a confined portion of air standing over water. The phosphorus combines with the whole of the oxygen, forming phosphorous and phosphoric acids, when the fumes come in contact with the water. It is a curious and remarkable fact that a gas of such extremely indifferent properties in the free state should, in combination with other elements, possess such active qualities. In combination with chlorine and iodine it forms frightfully explosive compounds, and the explosives used for blasting in mining operations, such as gunpowder, nitro-glycerine, or dynamite, are nitrogenous mixtures or compounds. Nitrogen forms five distinct oxides; one of them, nitrous oxide, N_2O, is a gas possessing a sweet taste and somewhat strange properties. It is commonly known as laughing-gas, and is not unfrequently used to produce insensibility in dental operations.

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[1] See page 69.

Atmospheric Air.

1 litre of air weighs at 32° F. and bar. 30 in.	1·2932 gram.
1 cubic foot of air weighs at 32° F. and bar. 30 in.	·0807 of a lb.

This term is applied to a mechanical mixture consisting, for the most part, of two gases, oxygen and nitrogen. Carbonic acid is also present in small quantity, and these three gases, more or less saturated with aqueous vapour, are essential to the existence of anim [illegible] vegetable life. Nitrogen occupies [illegible] nd oxygen about one-fifth [illegible] gases are in the condition of a mechanical mixture, and not of chemical combination, is shown by the ready manner in which they are separated by water, oxygen being more readily soluble than nitrogen. In fact a method of preparing oxygen has lately been used, depending upon the different solubility of the gases in water, or the more ready solubility of oxygen. Air is forced, by a powerful pump, into water, and the gases which are evolved when the pressure is partly removed are again subjected to the same process for eight times in succession. Mallet found that by this process he could obtain gas containing 97·3 per cent. of oxygen.

Carbonic acid rarely exceeds 1 part in 1,600 parts of air, and is usually present in the atmosphere in the ratio of 4 parts in 10,000. The results of the experiments of various observers have differed considerably in regard to the actual quantity of carbonic acid present in the lower regions of the atmosphere, that is to say, near the earth's surface, but not to such an extent as to depreciate their value, because it is quite possible that the proportion of this gas may vary according to the nature of the season and according to the healthy or vigorous condition of plant life. Small as the proportion of carbonic acid appears to be, yet the total quantity present in the atmosphere is said to be greater than all the free carbonic acid stored up in the seams of coal, together with that existing in combination with lime and other bases on the earth's surface. The higher we ascend above the earth's surface the larger is the percentage of carbonic acid. This is not in harmony with the law of gravity, and shows strikingly the power exerted by diffusion. The presence of carbonic acid in greater quantity in the higher regions of the atmosphere may be accounted for on the supposition that vegetation, where it flourishes, removes the gas from the lower stratum at a faster rate than diffusion from above proceeds. The air currents and winds also assist the movement of the atmosphere in a direction somewhat parallel with the earth's surface, and this tends to bring the carbonic acid in the lower stratum of the atmosphere more in contact with vegetable life. The vast increase in the production of all manufactured articles through the application of steam as a motive power, has been the means of leading men to search for the hidden treasures, in the form of seams or veins of coal, beneath the earth's surface. In order to convert water into steam, it is necessary to burn a substance which is capable of giving considerable heat. The various forms of carbon have been found to be the cheapest and most effective material for this purpose, consequently the seams and deposits of coal which contain sufficient carbon in a form available for heat-giving, and which do not contain too large a quantity of mineral matter, have been very extensively worked in order to satisfy the enormous demand. The combustion of this carbonaceous material, in the present day, must produce a volume of carbonic acid immeasurably greater than that which was generated before the introduction of steam power. Every ton of good coal containing say 85 per cent. of carbon, yields, when completely burnt, no less than 56,740 cubic feet of carbonic acid, or 3·12 tons of carbonic acid for every ton of coal. A large share of the carbonic acid in the atmosphere is generated by the respiration of man and animals. (See 'Respiration.') The burning of coal and other carbonaceous material also yields a large proportion, but the exhalations from volcanic sources, from springs, from seams of coal, and other natural sources, afford probably the largest supply. The carbonic acid produced by the respiration of animals is, possibly, increasing in quantity year by year, but to what extent it is difficult to determine with an approximation to accuracy. The volume of carbonic acid evolved by volcanic agencies is enormous, and that from springs is considerable; some of the latter, like those of Spa, Seltz, and Vichy, evolve many thousand tons annually. The springs which arise from, or which traverse carboniferous strata, collect by far the greater portion of the carbonic acid they hold in solution, from these strata. Coal and shale situated near the surface, as already stated, contain a large quantity of carbonic acid, and the water in passing through the coal or shale, or fissures in connection therewith, becomes charged with the gas under pressure, which escapes, for the most part, as soon as it reaches the surface.

In spite, however, of the apparent increase in the quantity of carbonic acid generated, there is no reason to believe that the actual volume distributed throughout the atmosphere at the present moment, is in excess of that which was present some thirty or forty years ago; on the contrary, it appears from the results obtained by some observers that it is gradually becoming less. The judicious application of artificial manures, such as superphosphate of lime, nitrate of soda, sulphate of ammonia, &c., now so largely used, will doubtless have the effect of increasing the yield of vegetable and cereal crops, and, in doing this, more carbon will be required to build up their structure, and as plants derive their carbon almost exclusively from the atmosphere, the more land is manured and cultivated, the larger will be the quantity of carbonic acid required. Under the influence of light, plants, trees, and all vegetable life possess the power of resolving carbonic acid (CO_2) into its constituent gases, assimilating the carbon and setting the oxygen free, thus a balance is maintained between the animal and vegetable worlds. Carbonaceous material is consumed by man and animals for the purposes of nourishment, and the sustaining of bodily heat, and the products of the oxidation of food afford, in their turn, the necessary material which plants require for the production of new plants and wood.

During the calcining of the carbonates of lime and magnesia, a very appreciable quantity of carbonic acid is generated, every 100 tons of limestone yielding 44 tons of carbonic acid, and 56 tons of lime (oxide of calcium). As a counterbalance against this loss of carbonic acid from the earth's surface, certain marine insects are continually constructing and building up fresh limestone, in the shape of coral reefs and other deposits.

The presence of carbonic acid in air may be shown by exposing a shallow layer of clear lime water for a short time, when it will be covered with a white pellicle of carbonate of lime or chalk. In order to estimate the actual quantity of [illegible] in the atmosphere, see page 149.

Small quantities of n [illegible] ammonia, and organic matter in the form of minute particles, some of which are in a state of decomposition, are found in the atmosphere. Marsh-gas is derived from the decomposition of organic matter, such as that going on in peat bogs, ponds, and other situations from which this gas is constantly evolved, but the largest quantity is given off by volcanoes and from seams of coal. The total volume of marsh-gas carried into the atmosphere from deep coal mines, especially the steam coal veins of South Wales and the North of England formations, must be very considerable. Although we are not aware of its being turned to account by plants, in order to build up their structure, or of any other means whereby its removal from the air may be effected, some such means may exist. The total quantity given off from all sources is, however, extremely small, when compared with the immense bulk of the atmosphere.

Ammonia finds its way into the air as a product of the decomposition of nitrogenous organic matter. Coal and other carbonaceous matter containing nitrogen and hydrogen in the state of combination, yield more or less ammonia during destructive distillation, and it is also given off during the decomposition of manurial and other organic matters. The results of the experiments of various observers respecting the quantity of ammonia in air, are not in any way concordant, but it is extremely probable that it differs according to the state of the weather, the amount of rainfall, and according to the presence of aqueous vapour in greater or lesser quantity. The mean of the analyses made by different observers would be nearly 70 parts of carbonate of ammonia in 100,000 parts of air, but this is probably much too high, and no number of parts expressing even an approximation to the truth can be given as an average of the quantity of ammonia present in atmospheric air. Some observers could not detect more than one part in a million, and much less than this has been found. Small as the amount may be, it exercises a very important influence on vegetation, as plants derive much of their nitrogen from that present in air in the combined form.

Aqueous vapour is always present in atmospheric air in more or less quantity, and it exercises a very material influence upon the well-being of animal and vegetable life. Evaporation from the surface of the sea, rivers, lakes, and other waters, as well as from the soil and all exposed damp material, is constantly going on, and the air always contains aqueous vapour though the quantity is variable. The degree of saturation depends upon certain circumstances, such as the prevailing temperature, the condition of the earth's surface whether dry or otherwise, the prevalence of wind, rain, and other terrestrial phenomena. The higher the temperature of the atmosphere, the greater is the quantity of aqueous vapour which it is capable of holding in suspension. When the temperature lowers, as it does at night after a warm day, a portion of the moisture condenses, and is seen in the form of dew upon the surface of plants and grass and other cold material. The quantity of aqueous vapour present in the air is an important point which often requires consideration in the ventilation and general working of a mine. The more aqueous vapour is present in the air, the less moisture will be taken up by the air currents in traversing the mine. The intake ventilating currents become raised in temperature in the act of passing through a mine, especially in winter, when it may rise 20° F, or still higher in all the working galleries, or throughout the working face of the coal. Should the air be dry at the time, or, in other words, if the aqueous vapour is very low, the air will, when raised in temperature, eagerly seize and take up all the moisture possible, and so render the coal-dust, timber, and all other exposed material in the galleries, headings, and working face, extremely dry. Under these conditions the air current is not probably charged with aqueous vapour except in confined situations, but the air in its ordinary condition usually becomes entirely saturated with water before it reaches the upcast shaft. Much moisture is, naturally, conveyed into the ventilating current by the burning of oil or candles, and the breathing of men and horses.

Numerous analyses of atmospheric air have been made by many investigators, and air from all parts of the globe has been subjected to analysis. It was found that the composition of air was remarkably constant, and the variations seldom exceeded ·2 per cent. of the oxygen. The following analysis represents, very nearly, the composition of air, no matter from what part of the world it has been obtained.

	By Volume	By Weight
Oxygen	20·88	23·00
Nitrogen	79·12	77·00
	100·00	100·00

The composition of air in its natural state, as given by Dr. Frankland, is :—

Oxygen	20·61
Nitrogen	77·95
Carbonic acid	·04
Moisture	1·40
	100·00

The best method for determining the composition of atmospheric air, is that of eudiometric analysis. A portion of air is introduced into a long glass tube, sealed at one end, into which platinum wires are fixed. The tube is graduated and of known volume. After the air has been introduced into the tube (which was previously filled with mercury), and measured, about one-half its volume of hydrogen gas is admitted, measured, and exploded by means of an electric spark, passed between the platinum wires referred to. The loss in volume caused by the union of the oxygen of the air with the hydrogen introduced, divided by 3, gives the number of volumes of oxygen present, and these divided by the number of volumes of air taken, and multiplied by 100, give the percentage of oxygen present ; the nitrogen is then found by difference. The percentage of oxygen in air can be determined with accuracy in a more simple manner, by using a short graduated tube of known volume called an 'absorption' tube. The tube is placed in a mercury trough, and filled with the liquid metal with the exception of the air required for analysis, which is measured :—afterwards, a few drops of a saturated solution of caustic potash, and a drop or two of pyrogallic acid solution, are passed up with a gas pipette, and the tube is then briskly agitated for five or six minutes, and the liquid reagents removed by a lump of moist cotton wool on the end of a wire, and let stand for 20 minutes to come to an even temperature, which is determined by a delicate thermometer hanging close by. The loss in volume divided by the original volume of the air, and multiplied by 100, gives the percentage of oxygen present.

The Atmosphere.

'The atmosphere' is the term used to designate the immense expanse or ocean of gaseous matter, which envelopes or surrounds the earth. The term atmosphere is also used to denote any gaseous matter which is enclosed within or surrounds a solid body, but it applies more particularly to the gaseous mixture of oxygen and nitrogen which surrounds our globe. The height of the atmosphere from the surface of the sea cannot be computed with accuracy, although it has been clearly proved that Marriotte's law is conformed to, in a great measure, by the gases which constitute the atmosphere, and whose density varies according to the pressure. It is calculated that the height of the atmosphere is about 45 miles, or 1-1728th the diameter of the earth. The variation in the height of the atmosphere was recognised at an early period, and the Florentine pump-makers were acquainted with the fact that water cannot be raised by suction from a depth of more than 30 to 33 feet. The reason of this was shown by Galileo, who pointed out that the pressure of the atmosphere was equal to the weight of 33 feet of water. Acting on this inference

Toricelli argued that if the atmosphere would support 33 feet of water, it would not support more than 30 inches of mercury, which is about 14 times as heavy as water. This he verified by experiment, and the instrument known as the barometer is constructed for the purpose of showing the pressure of the atmosphere, which, on the average, is equal to a column of mercury of 30 inches in height. The space above the column of mercury in a barometer, is called the Toricellian Vacuum, in honour of the inventor. The variations in the height of the atmosphere are very sensibly indicated by the barometer:—these variations make a difference in the height of the column of mercury of about two inches, so that when the atmosphere is low, the barometer may stand at 29 inches, and when it is high, at 31 inches. A column of mercury of 30 inches in height, exerts a pressure of 14·7 lbs. on the square inch, which is, consequently, the average pressure of the atmosphere.

The temperature of the atmosphere is not the same throughout, becoming colder as we ascend, until at length a height is reached where perpetual snow abounds. The line of perpetual snow is higher at the equator than near the poles, where it is, in fact, nearly at the sea level, while at the equator it is many thousand feet above the level of the sea. There is considerable variation in temperature on the earth's surface, as it is much hotter at the tropics than near the poles. These variations are due to the unequal heat of the sun in [illegible]rious latitudes of the earth. The difference [illegible] erature of the atmosphere thro[illegible] cribed, principally, to two [illegible]

I. A very small portion of the heat of the sun's rays is absorbed by the air in the higher regions of the atmosphere, owing to the fact that all gases are bad conductors of heat, especially in a condition nearly free from moisture, as is the case with air above the limit of perpetual snow. The greater portion of the heat of the sun's rays reaches the earth, and the temperature of the lower stratum of the atmosphere is elevated by the process called convection, or the warming of particles of air by contact with the heated surface—these ascending give place to others, and so on continually.

II. The gases of which air is composed, are in a state of continual motion brought about by mutual diffusion and air-currents. As the particles of air ascend, they become rarefied, and when air is expanded, heat is consumed in the exercise of elastic force, and the temperature lowers; conversely, the particles, of air in their downward progress to the earth, will regain the exact quantity of heat lost through power expended, owing to the work done by compression in assisting the molecular forces being converted into heat.

The density of the atmosphere affects the human body in a sensible degree, but does not influence the different material on the earth's surface to any perceptible extent. The atmosphere has weight and density, and consequently exerts a pressure which is equal on all sides and in all directions. The pressure on a man's body amounts to several tons, but is not felt because it is exercised, as just stated, in every direction. It is evident, therefore, that the pressure upon a working face of coal perhaps 1,000 yds. long and 5 feet deep, must be enormous. Now a reduction of one inch of barometric column, or, in other words, an equivalent lowering of the atmosphere, would materially reduce the pressure, which is much more perceptible when divided over a large area. It will be seen, therefore, that when a portion say 1-30th (if the barometer lowered one inch) of the pressure is removed, extending over so vast an area, the amount of gas which would be liberated in consequence must be, necessarily, very large. The height of the atmosphere determines the withholding or releasing of gas or fire-damp, and it behoves much care and watchfulness on the part of colliery officers when a sudden lowering of the barometric column takes place. We are not in a position to state that the volume of gas evolved under different barometric pressures follows a given law; practically speaking, it does not appear to, as a fall of half an inch seems to cause an inpour of gas much in excess of what one would expect. This seeming increase in the quantity of gas evolved may, however, be due to other causes; a decrease of barometric pressure impedes ventilation, and, consequently, the gases evolved are not carried away so quickly; the actual quantity may be, accordingly, only apparently excessive.

CHAPTER V.

HYDROGEN—WATER.

Hydrogen.

Atomic weight 1. Symbol H.

1 litre weighs at 32° F. (0° C.) and bar. 30 in. (760 m.m.) ·0896 gram.

1,000 cubic feet at 32° F. and bar. 30 in. weigh 5·5832 lbs.

THIS is the lightest of all gases, and of all the elements. It is consequently taken as the standard of weight, and the atomic weight of the elements is recorded in ratio to the number of times which they are heavier than hydrogen; thus carbon is 12 times as heavy as hydrogen—its atomic weight is, therefore, 12.

On account of its extreme lightness, hydrogen was formerly employed for the purpose of filling balloons, but owing to the cost of making the large quantity required, it has been superseded by coal-gas, which usually contains about half of its volume of hydrogen. It is supposed by some chemists to be the gaseous condition of a metal. The rare metals platinum and palladium, especially in a finely divided condition, absorb this gas in very large quantity.

Hydrogen gas is colourless, and has neither taste, nor smell when pure; but as commonly prepared it possesses a somewhat disagreeable odour, due to the impurities with which it is contaminated. Its specific gravity is ·0693, being about 14½ times lighter than air. It does not support the combustion of bodies generally, although oxygen appears to burn in it, but it is itself very inflammable. Oxygen does not burn in hydrogen—as hydrogen burns. A jet of oxygen in hydrogen appears to burn, but it is the film of hydrogen in immediate connection with the jet of oxygen which is burning. If breathed in its undiluted condition, at the first inspiration, one is struck with the ease with which it can be inspired, and the apparent slight exertion required, but it quickly causes a very disagreeable sensation. This is, however, due to the exclusion of oxygen from the lungs, and not to the properties of hydrogen, which is not poisonous, and may be breathed, when diluted with ten times its volume of air, for a considerable time without experiencing any ill effects. The colour of the hydrogen flame is pale blue. It is never found in the free state as the result of natural consequences, but is generated in nearly all instances in which organic matters containing hydrogen in the combined state are submitted to destructive distillation in the absence of oxygen. We have already noticed that coal-gas contains nearly 50 per cent. by volume—it is formed when steam is passed over red-hot iron—in the coking of coal, in the smelting of iron, and in numerous other operations in the arts and manufactures.

Hydrogen combines with [illegible] form water in the exact proportion [illegible] the former with one volume of [illegible] by weigh of the former, and eight parts by weight of the latter; and if the two gases be mixed in the above proportion, and ignited, combination takes place, water is formed, and the gases disappear entirely; this was first discovered by Cavendish. Hydrogen may be obtained for the purpose of experiment in a variety of ways: it is generally prepared by treating zinc clippings with sulphuric acid. One part of commercial sulphuric acid (oil of vitriol) mixed with seven parts of water, answers the purpose well. A Florence oil-flask or a bottle is partly filled with granulated zinc, or zinc clippings, covered with the diluted acid and furnished with a *tightly*-fitting perforated cork, through which a tube is inserted. The tube is conveniently bent so as to allow of the gas being collected over water. Pure hydrogen is prepared by decomposing a very dilute solution of sulphuric acid in water by the aid of the electric current. Hydrogen can also be obtained by the action of the metals potassium and sodium on water, and by treating iron and some of the metals with strong acid. No matter by what means it is prepared, great care should be taken in order to ascertain that all the air has been expelled from the vessel in which the gas is being generated before applying a light, else an explosion may occur, attended with serious consequences. This may be easily obviated by allowing a quantity of gas to escape before applying a light, and using a good sound cork, and with these precautions there is not the slightest risk attached to its making. This gas ll adapted for experiments on 'diffusion,' as it ter than any other gas, and, consequently, s more rapidly.

Hydrogen plays a very active part in the reduction of oxides to metals, and in the smelting of iron ores the reducing action of hydrogen is well known. The combining power or affinity of hydrogen is superior to that of carbonic oxide, and the former gas seizes the oxygen of the ore, and is not found free in quantity like carbonic oxide at the mouth of the furnace. As we before observed, hydrogen does not exist in nature in the free state, and was not supposed, until recently, to be present under any conditions in a coal mine. In 1874, while the author was engaged on the investigation of the 'gases enclosed in coal,' it was found that the deportment of marsh-gas in the presence of insufficient oxygen for complete combustion was not that generally credited. It was hitherto recorded that when marsh-gas (fire-damp) was exploded with too little air to burn the *whole* of the gas, that only as much marsh-gas was burnt as the air present would allow, the excess of gas remaining unaltered. The author found, however, that this was not the case, and that in all instances the whole of the marsh-gas was broken up, and when there was a deficiency of air for complete combustion, that carbonic acid, carbonic oxide, and free hydrogen were formed. The less the air which is mixed with marsh-gas and capable of forming an explosive mixture, the larger will be the volume of free hydrogen generated as the result of the explosion. The experiments carried out, and the results of which were confirmed by Dr. Meyer, of Germany, showed that with eight volumes of air and one volume of marsh-gas, some free hydrogen was formed on combustion and when the oxygen present was only one-half of that required to burn the whole of the marsh-gas, only carbonic oxide and free hydrogen were formed. It follows, therefore, that during every explosion in a coal mine large quantities of hydrogen are set free, and it is quite possible that this gas may be fired after its admixture with air through the 'backward suction,' and so cause a second explosion, hydrogen requiring only half its volume of oxygen for complete combustion, and it is ignited at a much lower temperature than marsh-gas. Hydrogen combines with oxygen, nitrogen, and carbon, and forms a variety of compounds, a few of which will come under consideration.

Water.

Symbol H_2O.

1 litre of water at 39° F. and bar. 30 in. weighs 1,000 grammes.
1 cubic foot of water at 32° F. and bar. 30 in. weighs 62·424 lbs.

Water is, chemically speaking, the oxide of hydrogen, and consists of two atoms of hydrogen combined with one atom of oxygen. If a jet of hydrogen be burnt in air or oxygen under a glass shade, drops of water, in the form of dew, will be found condensed on its inner surface. All the gases termed hydrocarbons, such as marsh-gas, olefiant gas, hydride of ethyl, &c., yield water when burnt in oxygen, the whole of the hydrogen being converted into that liquid. Pure water is a rare commodity, seldom, if ever, seen. That obtained by carefully distilling good rain water is nearly pure, but it is never free from impurities, although they are generally trifling. It is tasteless, inodorous, and transparent, having a slight blue colour, which may be seen by looking down a tube filled with water, standing on a white surface. It is a very neutral compound, and enters into combination with acid and basic oxides and salts; it also plays a very important part in determining the union and chemical combination of substances, as also, in some cases, their dissociation. Concentrated acids, which do not act on certain metals, do so energetically when water is added to them.

Water may be compressed into a somewhat smaller space by the application of great pressure; when it amounts to two atmospheres, according to Regnault, it loses nearly 1-20,000th part of its bulk, and, according to Perkins, it loses 1-12th of its bulk under a pressure of 200 atmospheres, or under a pressure of 2,940 lbs. to the square inch. Water expands by heat, and 1 cubic foot at 32° F. expands to 1·043 cubic foot when the temperature is raised to its boiling point, 212° F. (100° C.). The freezing point of water is 32° on Fahrenheit's scale and 0° on Centigrade. Water under increased pressure does not boil at 212° F., and it may be cooled below 32° F. without solidifying or becoming frozen. In a perfect vacuum (except aqueous vapour) water boils at about 32° F., and under a pressure of $1\frac{1}{2}$ atmosphere (22 lbs. to the square inch) it boils at 234° F. (112° C.). In the act of freezing, water solidifies, and, at the same time, increases in bulk about 1-11th part. This is the reason why water-pipes burst [illegible] weather, and so powerful is the act[illegible] conversion into ice that it [illegible]nse blocks of rock, and the crumbling and disintegration of the same is due, principally, to this cause. The density of water is not the same at all temperatures, nor does it vary according to a given law. The maximum density of water is at 39° F. (4° C.), and as the freezing-point (32° F.) is reached, it becomes less dense and lighter. Now the surface of water must be cooled to 32° F. before it will freeze, and the whole body of water must cool within 7° of this before the surface freezes, because at any temperature above 39° F., the warmer the water is, the less will be its density, and as the surface of a pond becomes cooled, say on a frosty night, for instance, the colder water sinks on account of its increased density, and lowers the temperature of the stratum of water beneath, which in its turn cools the stratum immediately below it, until, if it is a shallow pond, the temperature throughout is lowered to 39° F. When this is reached the water has attained its maximum density, so that after the surface stratum is cooled below this point it no longer sinks or diffuses downwards; consequently, as soon as the temperature falls to 32°, the surface of the pond freezes. Now the water at the bottom of a deep lake is influenced by the temperature of the earth prevailing at that depth, and is always nearly constant and much above the freezing-point, or, indeed, 39° F. As the surface of such a lake is cooled on a frosty night, the upper stratum sinks by virtue of its increased density, and the warmer water from below takes its place; but owing to the depth of the lake, and the lower stratum being warmed by the internal heat of the earth, the temperature of the mass of water does not fall to 39° F., and therefore the surface does not become frozen. This is the reason why deep waters are not covered with ice while shallow ones are thickly frozen. Water in the act of freezing gives off 72 units of heat, and when the ice is melted it absorbs the 72 units which it lost in changing from the liquid to the solid condition. The density of ice is less than that of water; on this account it is that a detached mass of ice floats on the surface.

The following table, from 'Watts' Dictionary of Chemistry,' gives the weights of certain volumes of water, in terms both of the metric system and of the system of weights and measures used in the United Kingdom:—

Grains	Cubic Centimetres at 4° C. grammes	Cubic Inches at 62° F.	Pound	Gallon at 62° F.	Cubic Feet at 62° F.
1					
15·432349	**1**	·061027		·0002201	·0000353
252·456	16·3861759	**1**			
7000·	454·3457969	27·727	**1**	·1	·016046
70000·	4543·457969	277·276	10·	**1**	·16046
436·495	28315·	1728·	62·355	6·2355	**1**

The thick unit figures show the equivalent of the weight or measure headed above them on the lines in which they are situated. For instance, the unit figure in the column headed '*pound*,' is on the fourth line, and shows by the figures in the same line under their respective headings, that 1 lb. of water is equal to 7,000 grains, or 454·3457969 grammes or cubic centimetres (1 cubic centimetre weighing 1 gramme), or 1 lb. of water measures 27·727 cubic inches at 62° F., or ·1 (1-10th) of a gallon at 62° F., or ·016046 of a cubic foot at 62° F., and so on.

The freezing point of water is lowered when there is a large quantity of salts in solution, and the larger the quantity the lower the freezing-point, but the ice will not contain the mineral or other matter which may have been in solution in the water. The density of water at 0° C. or 32° F. is ·99987, taking the density of water at 39° F. as unity, and ·99107 at 60° F. (15·5° C.). The density of all solids is taken from water as the standard, and by the 'specific gravity' of a compound, or of a body, is meant the weight of that body compared with water. In this country the standard density of water is taken at 60° F. Water evaporates at all temperatures, but the rate of evaporation is naturally controlled by surrounding influences. In the open air evaporation proceeds at a rate proportional to the temperature of the atmosphere, the amount of aqueous vapour in it, and the prevalence of wind, &c.

The evaporation of water produces cold, and if water be made to evaporate very quickly without the application of heat, as in a vacuum, for instance, so much heat may be removed by the portion which is converted into vapour as to cause the remainder to freeze. An ingenious apparatus, and at the same time a practical and cheap one for ice-making, invented and sold by M. E. Corré, Paris, illustrates very conclusively the statement made above. A decanter containing water is connected by means of an india-rubber cork to an effective air-pump, and the air exhausted—the vapour of water is then given off rapidly, because water boils at a much lower temperature in a vacuum. Inside the apparatus is a receiver containing sulphuric acid, which has a great affinity for water, and the acid seizes the vapour as quickly as it is given off, until, after a short time, so much heat will have been removed from the water by the vapour, that the temperature falls below 32° F., and a mass of ice results.

Water is decomposed by many metals at a red heat, the oxide of the metal being formed and hydrogen gas liberated. The quantity of gas given off would occupy an immensely larger volume than the water broken up, in fact the hydrogen of water would in the free state occupy 1,240 times the space. It is probable, therefore, in cases of boiler explosions where the water has been very low, and cold water admitted, perhaps, upon red-hot plates, that the force of the explosion was due as much to the gas generated as to the pressure of the steam. Iron decomposes water readily at a red heat.

Water is very widely diffused in nature, and its great importance and absolute necessity for the well-being of animals and vegetable life renders it probably the most useful of all compounds. In the liquid condition it constitutes oceans, rivers, lakes, streams, and springs, and in the solid state, as ice or snow, it forms those great masses known as glaciers and icebergs, and also the immense masses in the region of perpetual snow and in the Arctic regions. Water occupies more than three-fourths of the entire surface of the earth—the oceans occupying by far the largest area. It is evolved in the state of vapour from volcanoes, from all organic matters containing hydrogen which undergo combustion, and from hydrogenised organic matters undergoing putrefaction or decay. Water finds its way to the surface in a boiling state in Iceland, California, and in volcanic districts—the waters at Bath are nearly 120° F. throughout the year. It is found in all rocks and minerals to a greater or lesser extent, and is also present in the solid condition in a great number of natural and artificial chemical compounds as water of crystallisation or constitution. Water is usually divided into four classes—rain-water, spring-water, river-water, and sea-water, but a description of these would be out of the limits of this treatise.

Water used for the purpose of generating steam in collieries is obtained either from brooks, rivers, or colliery drainage. Waters from these sources contain a variable amount of mineral and other matter in solution and suspension, and they all leave a greater or lesser residue on evaporation. The chief mineral constituents of these waters are carbonate and sulphate of lime, the latter compound being present in greater quantity in the waters pumped from collieries, or drained out of levels. Some surface springs, and rivers of the coal measures are so free from excess of carbonate or sulphate of lime, that they are very suitable for generating steam. In the majority of instances the waters used for raising steam at collieries are very hard, and rarely free from sulphate of lime. Water which percolates through the upper strata and rocks of a coal basin usually comes in contact with thin, pellicle-like layers of gypsum or sulphate of lime, and sometimes with sulphate of iron, produced by the oxidation of pyrites; these enter into solution, in addition to carbonate of lime, which becomes dissolved by the aid of the free carbonic acid of the coal strata. The more bituminous the coal is in the neighbourhood, and, as a rule, the more sulphur it contains, the harder will be the waters which rise from any depth. The author has examined waters from the coal measures which contained more than 70 grains per gallon of sulphate of lime, which, together with the carbonate of lime, reached a total of more than 100 grains per gallon; others varied from traces only of sulphate of lime to 10, 20, 30 or more grains per gallon.

Water used for raising steam should not contain more than 20 grains of solid matter per gallon, and much less would be preferable, and not more than 2 or 3 grains of sulphate of lime should be present. Rain-water, when it can be obtained in quantity, is well adapted for generating steam.

Carbonate of lime is held in solution in water as bicarbonate by an excess of carbonic acid, and is thrown down in the state of fine white powder when the water is boiled. Sulphate of lime is soluble in about 400 parts of water, but it is less soluble than this in boiling water. When water containing these salts in solution is boiled, the carbonate of lime is quickly thrown down, and as the water evaporates sulphate of lime is precipitated also. The finely comminuted carbonate of lime as it travels in suspension in the water (in a steam boiler, for instance) comes in contact with the iron plates of the boiler, and forms a slight scale by admixture with the muddy matters of the water. As the compounds in solution become more concentrated sulphate of lime is thrown down, together with more or les [illegible]. The sulphate of lime is precipitated i [illegible] m (as hydrated sulphate of lim [illegible] to the carbonate already precipitated; more carbonate of lime is continually being deposited, and more sulphate of lime constantly cements it together. As soon as a scale of some thickness is formed, say ¼ inch, the temperature of the inside of it, next the boiler, becomes higher and higher as fresh matter is deposited, until the water of crystallisation or constitution of the sulphate of lime has been expelled together with that present in the hydrated silicic acid, and the mass shrinks and sets with extreme hardness. As the scale thickens it becomes harder and harder, owing to the increased heat to which it is subjected in contact with the boiler-plate, until, at length, if it be left undisturbed for a time, it is almost as easy to chip the boiler plate as the deposit thereon. The author has examined boiler-crust taken from the fire-box top of locomotives, which it was found impossible to remove internally, and which was certainly as hard as flint; silica formed a large portion of this deposit. Waters which contain sulphate of lime in about half the quantity of the carbonate present, in addition to silica, appear to form the hardest boiler-scale.

The greatest care should be taken in the selection of water for steam-generating purposes, else there will be continued difficulties experienced through the formation of boiler-scale, as well as an excessive consumption of fuel, and wearing, or rather burning, of the boiler-plates; and to this must be added the danger of an explosion taking place.

Numerous compounds have been extolled for their beneficial action in preventing the formation of boiler-scale, and for maintaining the precipitated mineral and other matters in a state of suspension in the water. There is scarcely a town of any importance in the mining and manufacturing districts which does not possess one or more factories where some liquid or solid composition is made for preventing this corrosion by water. It is scarcely necessary to add that few, if any of them, are worth the price charged; but from the apparent readiness with which they are disposed of, it would seem that there must be large quantities sold. The presence of organic matter materially prevents the formation of boiler-scale, as it hinders the crystals of sulphate of lime forming a cement with the other mineral matter. In the absence of vegetable organic matter, it is extremely difficult to prevent boiler-scale, and we are not going too far in stating that it is almost impossible to get any solid or liquid compound capable of removing and preventing the incrustation which shall not at the same time attack the boiler-plates. As the results of numerous experiments made with some of the liquid and solid 'boiler compositions,' the author found invariably that those which were most efficacious in removing the scale showed considerable activity in attacking iron, although they were 'warranted not to attack boiler-plates.' Oak-bark, spent tan, green oak wood, and all vegetable substances containing tannic acid, or like astringent principles, answer the purpose of removing boiler-scale, and of preventing its formation, but they attack boiler-plates and destroy them, in some instances as much as the scale does.

A great many of the solutions sold under the name of *boiler composition* are nothing more than decoctions of oak-bark, mahogany sawdust, oak sawdust, pine or fir-wood, spent tan, &c., whose action depends upon the quantity of tannic acid and other analogous principles. All the solutions, when used in sufficient quantity, for many of them are little else than water, remove or prevent boiler incrustation to a greater or lesser extent; but they all attack iron, and so searching is their action that the iron scales (magnetic oxide) around rivets, straps, and bolts, are so completely removed that leakage results. This does not, however, occur with many of the liquids sold, as they are usually so diluted as to require a much larger quantity than is generally added before any action takes place at all.

The major portion of the solid material sold as boiler composition is about on a par with the liquids. These compounds are composed of various vegetable and animal refuse, leather cuttings, hoof parings, hoofs of sheep, pigs, &c., fused into a mass, various mixtures of wood and vegetable fibre, &c. Others are of mineral constitution, containing one or more chemical compounds, in addition to other matter added to give bulk and weight; among the chemical compounds are chloride of ammonia (sal ammoniac), alkaline carbonates in the form of soda ash, &c., chloride of barium, hyposulphite of soda, caustic soda, &c., to which are added indefinite compounds in the shape of grease, plumbago, gas liquor, creosote, &c. Metallic zinc suspended in the boiler is said to give good results. Blacklead has been used for the purpose of polishing the inside of the boiler-plates, but it becomes washed off after a time; it is a constituent of many of the solid 'boiler compositions,' and tends materially to prevent the scale becoming hard. A mixture of linseed oil and caoutchouc has been recently recommended for coating the inside of boilers, to prevent the scale adhering to the iron, and is said to answer well.

Of all the preparations used and recommended for the purpose of removing and preventing incrustations in boilers, the older remedies, simple as they are, are about the most harmless and certainly not the least effective; of these, potatoes, either good or damaged, swedes, mangolds, carrots, parsnips, or any other vegetable which is too far gone for human consumption, have been used with more or less success. In the winter and spring, when old and damaged potatoes are cheap, they are equal to any of the 'compositions' for the purpose of removing incrustation. One difficulty attending their use is that of introducing them into the boiler under steam, but the same difficulty is experienced with the solid composition, and might easily be obviated. Swedes answer the purpose almost as well as potatoes—a rather larger quantity being required. These vegetables do not act upon boiler-plates with nearly so much energy as most of the 'boiler compositions,' while the latter, which do not attack iron sensibly, are generally inferior in their action upon boiler-crust. Carbonate of soda and caustic soda are much used for preventing boiler-scale.

Numerous methods have been proposed in order to get rid of the solid matters in water previous to its introduction into the boiler, on the principle that 'prevention is better than cure,' which is undoubtedly true in this case. There is, however, some difficulty attached to this removal of the dissolved contents of a water, having special reference to carbonate and sulphate of lime. We have already noticed that carbonate of lime is chiefly held in solution as bicarbonate—carbonate of lime ($CaCO_3$) being soluble in water to the extent of two or three grains per gallon only, but in the state of bicarbonate twenty or thirty grains per gallon may be held in solution. By the addition of caustic lime, or lime-water, which is simply caustic lime dissolved in water—the excess of carbonic acid over that required to form the carbonate combines with the quicklime (which after solution in water exists in the form of hydrate, CaH_2O_2) and forms carbonate of lime. As stated, carbonate of lime is practically insoluble in water, and after standing for some time, water which has been treated with lime, as in Dr. Clarke's process for water-softening, becomes clear, and the milky-white powder settles to the bottom. This process is quite practicable and inexpensive, but it requires two tanks of considerable size: there is, however, little or none of the sulphate of lime removed, and this compound requires to be precipitated by other means. This is accomplished by adding to the water a small quantity of chloride of barium, which forms an insoluble compound with the sulphuric acid of the sulphate of lime, while the chlorine of the chloride of barium enters into combination with the lime. The chloride of barium requires to be added in known quantity to a known volume of water, as it is an expensive salt, and if added in excess would be objectionable.

It will be seen, therefore, that in order to apply the chloride of barium systematically, it is requisite to know approximately how much sulphate of lime the water contains. It is also necessary to know the amount of carbonate of lime present previous to the addition of lime water, because the latter must not be added in excess, otherwise a lime crust will be formed in the boiler. The process of precipitating the bicarbonate of lime by lime, and then throwing down the sulphuric acid by chloride of barium, has been *recently* termed De Haën's process.

The chloride of lime (formed by the union of the chlorine of the barium chloride with the lime set free from the sulphate) remains dissolved in the water, and does not become thrown down by boiling, and, according to De Haën, it is unnecessary to blow off the boilers more often than once in six weeks, unless continually in work, when once a fortnight would be more advisable. Theoretically this is correct and practicable, as no calcic chloride (chloride of lime) will be deposited in a boiler after a month's continual working, provided the quantity of sulphate of lime present in the water before precipitation is not excessive; if it is excessive, then the corresponding quantity of chloride of calcium formed will be proportionately great. For instance, take a water containing 15 grains of sulphate of lime per gallon, it will require 23 grains of chloride of barium to remove the sulphuric acid (of the sulphate of lime), and there will remain in solution in the water rather more than 12 grains of chloride of lime per gallon. A boiler in continual work, night and day for a week, evaporates under ordinary circumstances seventy times the quantity of water which it holds; at the end of this time, therefore, the quantity of chloride of calcium present in the water in the boiler will become concentrated to the extent of 840 grains per gallon.

Some time ago the author was about to recommend the adoption of the lime and barium process on a large scale in the case of a water containing about 12 grains of sulphate of lime and 17 grains of carbonate of lime per gallon. Before doing this, it was thought desirable to carry out a series of experiments with a view to determine the action of chloride of calcium and other soluble salts, as chloride of sodium (common salt) upon boiler-plates. The result of the experiments showed that the presence of chloride of calcium, even in small quantity, had the effect of materially hastening the oxidation of iron in the presence of very small quantities of dissolved gases. When clean iron plates were immersed in boiling distilled water, to which chloride of calcium had been previously added, the action on the iron was almost imperceptible, and as long as boiling distilled water was added to make up the loss due to evaporation, the iron plates remained scarcely acted upon. When, however, cold distilled water was added to replenish that evaporated, then the oxidation of the iron plates proceeded rapidly. The experiments were varied in such a manner as to represent the injection of cold water to keep up a boiler supply; and the results showed that the presence of chloride of calcium materially assisted the oxidation. It was also found that chloride of sodium (common salt) acted in a similar manner, as also chloride of magnesium; in fact, all the soluble chlorides used were found to assist the oxidation of iron in the presence of very minute quantities of dissolved gas.

It may be argued that the water injected into a boiler is very rapidly heated to the boiling point, and that the dissolved gases are very quickly driven off. The greater portion of the latter are quickly expelled, but some of the gases are most obstinately retained, and oxidation of the boiler-plates proceeds as long as there is a trace of dissolved oxygen present. When a solution of the chlorides referred to is boiled in the presence of iron, no decomposition of the chlorides takes place, but it is probable that the chlorine of chloride of calcium, &c., assists the oxidation of iron in the presence of dissolved oxygen, by momentarily combining with it, and as quickly recombining with its original base. A boiling neutral solution of these salts, after metallic iron has been added, becomes slightly alkaline.

There would be a very large proportion of soluble chlorides present in a boiler after one week's continual work, if the lime and barium process were employed, and the result would be that the ill effects of sea water upon boilers would, to a very great extent, be experienced. We do not anticipate that the action of these salts upon the boiler-plates would be so serious as that of a thick boiler-scale; but, after taking into consideration the expense attached to the providing of settling tanks, the continual use of an expensive chemical like chloride of barium, and the slight attention which the process may be expected to receive at the hands of stokers or inexperienced engine-men, we are of opinion that the cure is little better than the disease.

The necessity, therefore, of providing a water suitable for boiler use, in the first place, is one of paramount importance, and should not be neglected, and it will amply repay, in the end, any reasonable outlay in procuring a good water for this purpose, and one as free as possible from excess of lime-salts. Where no other than hard water can be obtained, and such must be used for generating steam, some arrangement should be made for condensing the exhaust, so as to limit, to a great extent, the use of the hard water.

CHAPTER VI.

CARBON—GRAPHITE—WOOD CHARCOAL—COKE—GAS CARBON—CARBONIC ACID, OR DIOXIDE—CARBONIC OXIDE.

Carbon.

Symbol, C. Atomic weight, 12.

CARBON exists in the free condition as a solid, in an almost absolute state of purity in the diamond. Various other kinds are found native mixed with more or less impurity. In combination with other elements, it forms the great mass of all living plants and animals, so much so, that nothing living, either in the form of animal or vegetable life, could exist without its presence. All the varieties of carbon are combustible; some of them, however, as the diamond, graphite, and gas carbon, require the heat of the electric arc before they are dissipated in vapour. The gaseous product of complete combustion is the same at all temperatures, viz., carbonic acid. The common forms of carbon, such as charcoal, coke, and anthracite coal, are [illegible] ent; the more hydrogen there is [illegible] the ease and rapidity with [illegible]

[illegible] when the diamond and [illegible] forms of graphite are very hard and metallic in appearance, and good conductors of electricity. Carbon is found in the crystalline and amorphous condition. The diamond has been prized as a gem for ages, and, without doubt, it is by far the finest of all gems. It is the hardest substance known, but does not appear to be always of the same density, as the specific gravity is said to vary from 3·3 to 3·52. Owing to its great hardness it will scratch any other substance, and is peculiarly adapted for cutting glass. A natural crystal is employed for this purpose, because a keen edge obtained by polishing or cutting a diamond only scratches or etches glass. In polishing or cutting diamonds for gems, diamond powder is employed, as no other substance is sufficiently hard for the purpose, not even the hardest kinds of emery powder. Diamonds which possess neither lustre nor transparency are not so rare as those of finer quality, and are reduced to powder in order to cut the latter. The diamond is found crystallised in various forms belonging to the regular system, usually in the form of the octahedron, and when most pure it is colourless and transparent, of beautiful lustre, and high refractive power. Its lustre is much increased after being well cut. Diamonds are found of various shades, such as yellow, black, red, and brown, but the latter, except in rare instances, are not equal in value to the former. The diamond has been procured of late years in increased quantity, and the diamond fields of Southern Africa have turned out to be very productive. The diamonds obtained have, however, a tendency to a light shade of yellow colour, and are not therefore so highly prized as the clear Golconda gems. Diamond is the purest kind of carbon known, but it is not absolutely pure, as the finest transparent variety contains a trace of ash, which is present in estimable quantity in the coloured forms. It is found principally in Brazil, India, the island of Borneo, and Southern Africa, in clayey soil which is the product of the washing and disintegration of rocks belonging to the older formations. The black diamonds have been recently employed with success for the cutting portions of instruments used for boring in search of coal, paraffin oil, &c.

Graphite.—Several native varieties of carbon are included under this term. Some of them are crystalline, others are opaque, of a blackish-blue colour resembling steel. They are found imbedded in quartz, and in thin veins between rocks. The crystalline varieties are not of much interest. Amorphous graphite, or plumbago as it is termed, has been found at Borrowdale, in Cumberland, some parts of Germany, and largely in Siberia and in Ceylon. It is of a black-grey colour, and produces a black streak on paper, and, on this account, it is much used for making drawing pencils. The finest quality is employed for this purpose, the more common and inferior kinds are ground up and cast into moulds, and sold as a coating to protect iron from rust, and to give it a shiny black polish. It is much used on wood and other material for the purpose of reducing the friction of rubbing parts. It is also employed for lining small furnaces and making crucibles, as it is indestructible at such temperatures as are usually employed in them; in fact it is only readily combustible in the electric arc. Graphite, like many coals, is acted upon by oxidising reagents. Brodie has shown that it is converted into graphitic acid by the repeated action of chlorate of potassium and nitric acid.

Wood Charcoal.

Wood charcoal is the residue of black or brownish black porous material, which retains the form and bears the original markings of the wood from which it is produced. It is very light and porous, and the yield from ordinary dry wood is about 70 per cent. by volume, or 20 to 25 per cent. by weight. There are two principal methods of making wood charcoal; the older, and the one still adopted on the large scale, is that of piling the wood end upwards in two and three tiers of a circular form from 12 to 18 feet in diameter. Different styles of building are adopted in different countries. In this country a bundle of hoop or hurdle shavings, and the ends of unburnt wood from a previous pile, are put in the centre, and the wood, which is cut in lengths of 2 ft. 2 in., is carefully and neatly arranged around, some of the stoutest wood being placed near the inside. The cord wood as it is termed is piled in a slanting position and leaning top inwards, the angle diminishing from the inside outwards, until, on the circumference, it is about 45°. After stacking, the pile is carefully covered with the dust and ashes of a previous burning—the old charcoal pits being always used where practicable over again, and the deficiency of covering material made good with turf. After the pile has been fired, every care is taken not to admit an excess of air, which is regulated by small holes opened near the base of the pile, and closed at will by the burner. The pile is carefully protected from currents of air and wind, by means of brushwood hurdles and gorse, or other close material. The quantity of air admitted is regulated by the practical experience of the burner, who relies, for the most part, on the colour of the smoke emitted. As soon as the pile is carbonised to an extent shown by the emission of blue smoke from the holes in the base, every vent is securely closed, and the pile rendered as impervious to air as possible. The pile is left undisturbed for some days and then opened, the charcoal quenched with water, and the hot mass protected from the atmosphere during the operation.

The other method to which we have referred is that of carbonising wood in iron retorts. The volatile products are condensed and turned to account, and large quantities of wood spirit or methyl alcohol, and wood vinegar are obtained in this way. The small weight of charcoal compared with that of the original wood from which it is made, shows that the carriage of the wood from long distances would be too costly a matter, and this is naturally the greatest drawback to the practice of charring in ovens. On this account it is that the old method, applicable to the burning of wood on the spot, is still practised in this country. The average composition of wood charcoal is about that shown by the following figures:

Carbon	86·5
Hydrogen	2·5
Oxygen and nitrogen	1·5
Ash	3·0
Water	6·5
	100·0

The gases occluded in charcoal consist of oxygen, nitrogen, carbonic acid, and carbonic oxide. Wood charcoal absorbs a large quantity of gas, and those kinds made from the softer woods, and which yield, after burning, a very porous charcoal, possess in a high degree the property of absorbing gases. Wood charcoal retains, after charring, more or less of the gases before enumerated, and its pores are otherwise filled with atmospheric air. In order, therefore, to determine its absorbent power, it is necessary to ignite it and let it cool out of the reach of air. Charcoal shows considerable activity in determining the combination of gases, and its remarkable deodorising properties, or power of destroying effluvia, are, doubtless, due to the power which it possesses of assisting the combination of gaseous and other matters with oxygen, and so destroying their offensive condition. Charcoal is, on this account, much used for respirators, general deodorising purposes, and for filtering water and other liquids; in these latter uses animal charcoal is preferable to that made from wood.

Coke.

Coke is charcoal made from coal. Those coals which are adapted for burning into coke are of bituminous quality, and contain a high percentage of hydrogen and oxygen. Many varieties of surface coal, that is, coal which is won at a short depth from the surface, or from a level in the side of a mountain, are often of a soft and porous character, and crumble, by transit, to such an extent, as to be unsuited for household purposes, owing to the quantity of small coal incidental to handling and carriage. They may be of excellent quality, however, and well adapted and prized for the coke which they yield. The coke which is produced in gas works is not of first-rate quality, as more or less cannel or highly bituminous shale is mixed with the common gas coal, in order to increase the illuminating power of the gas generated. Scotch cannel shales, which yield a large quantity of gas, but which contain 20 or even 30 per cent. of mineral matter or ash, are frequently used with bituminous coal for gas-making.

Good coke is of metallic appearance, hard and porous, showing a striated fracture produced by the water added to cool it. Coke differs very much in structure, appearance, and density, and its value for metallurgical and other purposes cannot be estimated from its appearance. Some coke is dense, dull in appearance, and hard, while more is blackish, soft, and tender. Those mostly prized for metallurgical purposes are dense, compact, and somewhat incombustible, and are, usually, metallic in appearance, and in striated masses, and so hard as to be capable of resisting considerable crushing weight. The following analysis, by the author, represents the composition of coke:—

Carbon	90·68
Hydrogen	·52
Oxygen and nitrogen	1·09
Sulphur	·96
Ash	6·75
	100·00

Coke always retains some of the hydrogen, oxygen and nitrogen, originally present in the coal, but the percentage is, relatively, very small. Sulphur is also an ingredient of coke, existing as sulphate or in combination with iron as sulphide. Some cokes when broken show the red spots originally occupied by nodules of pyrites, and which are almost entirely in the state of oxide of iron. All cokes contain more or less water, which varies from less than ½ per cent. up to 5 per cent. The percentage of water will depend, naturally, upon the manner in which the coke has been 'quenched,' and whether it has been exposed to the influence of rain. Coke is capable of taking up much water when immersed in that liquid, somewhat in the same manner as a sponge does, but the greater portion evaporates again, and leaves the coke in a moderately dry condition.

The quantity of ash in coke varies according to that present in the coal from which it has been made. As previously noticed, it will be greater than that in the coal, because the matter which escapes does not contain any ash, or, in fact, rarely more than traces. The amount and composition of the ash of coke are very important considerations in determining its value for metallurgical purposes, as well as the quantity of sulphur which it contains. The quantity of phosphorus in the form of combined phosphoric acid is another important consideration, and, although its presence in the ash of coal and coke has not received the attention it deserves, it doubtless will when the Bessemer process of steel-making becomes more generally adopted, since the presence of phosphorus is detrimental to the metal produced. Coke which gives a red or pinkish-red ash fuses readily and forms a hard clinker, especially if silica be present.

When steam is passed over red-hot coke it is decomposed into its constituent gases (oxygen and hydrogen), which, at the moment of becoming nascent, combine with the carbon of the coke, and marsh-gas, carbonic oxide, carbonic acid, and free hydrogen are formed. Various attempts, founded upon this fact, have been made from time to time, with a view to remove the sulphur from coke. Some of these experiments have been attended with considerable success so far as the removal of a portion of the sulphur is concerned, but the waste of carbon by oxidation was always considerable. Coke is employed as fuel in a great many metallurgical operations, and the presence of sulphur is detrimental to the production and refining of metals generally, so that if coke could be desulphurised economically it would be much better suited for such purposes. A patent was obtained in this country for the desulphurisation of coke by means of steam, but the loss of carbon was so great compared with the small gain in the proportion of sulphur removed, that the method has not been adopted. Common salt (Calvert's patent) has been used, and mixed with coal before coking, but no favourable result appears to have attended its use. Coke has also been heated below redness in atmospheric air at the ordinary pressure, and under increased pressure, but the results obtained by Phillipart, who conducted the experiments, do not justify the employment of either process on the large scale.

These conclusions are entirely borne out by theory, and could be arrived at without experiment after, once for all, knowing the relative affinities of carbon, hydrogen, and sulphur for oxygen. The affinity of carbon for oxygen is far greater than that of sulphur, and greater, too, than that of hydrogen, as will be seen from the composition of the gases obtained by passing steam over red-hot coke or charcoal. In the first place about 50 per cent. of the gas consists of hydrogen, the remainder, with the exception of about 1½ per cent. of marsh-gas, being oxy-carbon compounds—carbonic oxide and carbonic acid. By the application of the 'steam' process, the sulphur might become converted into sulphuretted hydrogen (SH_2) by combining with the nascent hydrogen, but the whole of the oxygen would be used up by the carbon to form carbonic oxide and carbonic acid. If, therefore, coke could be desulphurised by the 'steam process,' by the use of a small volume only, the process might become useful and be employed on a large scale; but this cannot be accomplished, as it requires the application of steam for a considerable time in order to remove 75 per cent. of the sulphur, and in doing this about 50 per cent. of the coke would be converted into carbonic oxide and carbonic acid. It stands to reason, therefore, that all processes dependent upon oxidation with atmospheric air must fail, since the affinity of carbon for oxygen is so great as to render it a matter of chance almost whether any sulphur shall be oxidised at all, and it is not probable that any method will be devised which shall be sufficiently remunerative or economical for practical application. The method of coking is too well known to need much description. Coke is made in ovens of various forms, but those generally used in this country consist essentially of fire-brick chambers provided with a flat and somewhat sloping bottom and arched roof. Two openings are furnished, one serving the double purpose of a chimney and an opening for the introduction of the coal, and the other consists of a large door in front for removing the coke. The sides of the internal walls at right angles to the door widen slightly towards it, so as to admit of the coke being more easily drawn in mass, after the completion of the carbonising operation. A rail connected nearly at right angles with two bars which meet in a bend at the outside of the oven, is placed on the floor of the same, and the charge is introduced; the exit door, which is either hinged or supported by a counterpoise weight, is closed so as to admit very little air, and this only from near the top. Sufficient heat is left from the previous charge to start the combustion of the next, and the air is so regulated that combustion shall proceed from the top downwards. When the carbonisation is complete, the door is opened, and by the aid of a chain, one end of which is in connection with the iron frame placed on the bed of the oven, and the other end is joined to a windlass worked by a steam-engine or other power, the whole charge is drawn at once. The coke is immediately quenched with water, and a fresh charge placed in the oven without delay. The products of combustion are in this manner lost, that is to say, they pass off into the air unutilised. Much heating power could be obtained from the gases evolved in the process of coking, and by the addition of a little air to ensure complete co[illegible] heat produced could be em[illegible], &c.

A very fine row of ovens has recently been constructed at the London and South Wales collieries at Risca, Monmouthshire, over which boilers have been arranged for raising steam, in order to make the waste products of coking afford the necessary heat. A great many forms of coke ovens have been patented in this country and elsewhere, but few of them have been much adopted.

The nature of the coke obtained from coal depends upon the character of the coal and the manner in which the coking operation has been conducted. The higher the temperature at which coal is carbonised the greater the yield of coke, provided the time occupied is not extended too long. In order to get a hard coke for high-blast-furnace use, the period of coking is prolonged and the temperature is usually high. Some considerable skill is required to produce a really good yield under these circumstances, and much practice is necessary in order not to waste too much of the carbon in getting the required product. The very high percentage of ash which is often found in coke made from large coal which contains a relatively small proportion, shows that there must be a considerable and unnecessary loss of carbon. It is quite possible to produce from good bituminous coal a coke of moderately hard quality, and one which shall burn with facility; and it is possible, too, to get from the same coal by prolonged heating at a high temperature a coke which is so incombustible as to require a most powerful blast to burn it at all, and even then with extreme slowness.

Gas-carbon is found in the top of retorts in which coal-gas is generated, and may be obtained likewise by adding charcoal to molten iròn and extracting it after the iron is cold. It is also obtained from blast-furnaces. It is of metallic appearance, very hard, and somewhat porous. Gas carbon is a good conductor of electricity, and is used in the Bunsen battery for the negative element. Extremely hard and dense kinds of carbon can be artificially prepared from organic compounds.

Lampblack.—All dense hydrocarbons, when supplied with insufficient air for complete combustion, deposit more or less soot or carbon, especially when they are in the state of vapour, and the vapour is only partially consumed. The carbon thus formed is deposited in an extremely comminuted form, and it is extensively used as a black pigment, and in the manufacture of printing ink. It is manufactured from pitch or resin in the following manner: a large pot of cast-iron containing the carbonaceous material is heated in a furnace, and the vapour passes over into a kind of receiving chamber, where it becomes ignited, the air being so regulated as to produce the largest possible deposit of carbon, which falls either in a chamber covered with fibrous material, or fitted with an iron bell, which can be raised or lowered at will, and which fits the chamber sufficiently close to bring down the soot or lampblack in its descent. Another method is to condense the product in a series of chambers, and that obtained in this manner is more pure and free from oily matters than lampblack prepared in the former process.

Animal Charcoal, or bone black, is obtained by calcining bones. It is a fine black powder, containing about 70 per cent. of phosphate of lime. The carbonising process is conducted in cast-iron cylinders; a large quantity of offensive vapours are given off, and the charcoal which is mixed with the phosphate of lime is so finely divided as to give it a fine black appearance. It is much used as a decolouriser and for filtering purposes, and by some distillers in order to remove fusel oil from spirits. It is employed in the refining of sugar, and forms the filtering material used in common water filters. Bone charcoal which has been used for the purposes enumerated can be purified and re-used after calcining it. Waste bone black is treated with sulphuric acid (oil of vitriol), and sold as a manure, which is very efficacious when applied to root crops and leguminous plants.

Carbonic Acid, Carbonic Dioxide, or Carbonic Anhydride.

Symbol CO_2. Molecular weight 44.

One litre of the gas at 0° C. and bar. 760 m.m. (30 in.) weighs 1·971 grammes.

One cubic foot of gas at 32° F. and bar. 30 in. weighs 0·12845 lb.

This gas is the choke-damp of the miner, and the fixed air of the ancient chemist. It is present in air in the next largest proportion to nitrogen and oxygen, which are simple gases or elements, while carbonic acid is a compound gas consisting of two elements combined, in the proportion of one atom of carbon united with two atoms of oxygen. At the moment of combination these three atoms are condensed in volume so as to occupy the space of only two atoms or volumes.

	Composition by Weight	Composition by Volume
Carbon	27·27	1
Oxygen	72·73	2
	100·00	2 volumes combined.

This gas is always produced when compounds containing carbon are burnt in air or oxygen. It is evolved in immense quantity from volcanoes and from fissures in rocks which are in connection with subterranean channels. It is the product of the oxidation, or slow combustion, of organic compounds in the lungs and blood of animals, and is generated in all instances of organic matters undergoing putrefaction or decay.

In the conversion of organic remains into coal, carbonic acid was largely formed, as can be proved by the presence of this gas in such appreciable quantity imprisoned in the pores of the coal. A glance at the results obtained by subjecting various coals to a process of distillation at comparatively low temperatures, *in vacuo*, given in the tables pp. 42–47, will show to what an extent carbonic acid is present in coal, especially in those of bituminous quality. It had, in great measure, been removed from the coals which were obtained near the surface, by the action of water, which is capable of dissolving this gas in quantity, especially under pressure. At the ordinary pressure at 15° C. (59° F.), water dissolves about its own volume of carbonic acid, but seven or eight times its volume may be dissolved under pressure. The occluded gases in all coal contain carbonic acid. During the calcining process, carbonate of lime evolves 44 per cent. of carbonic acid, and all waters contain it in greater or lesser quantity. It is employed in the manufacture of artificial waters, such as soda water, lemonade, Seltzer, &c. For this purpose the gas is obtained by decomposing limestone with hydrochloric or sulphuric acids, and subsequently passing it through water to wash it, in order to remove any vapour of acid. It is then forced under pressure into the prepared water, and bottled by the aid of machinery.

Carbonic acid is produced during the fermentation of wine, beer, and other beverages, and is incidental to the conversion of sugar into alcohol. It is one of the heaviest gases usually met with, being rather more than 1½ times as heavy as air, and 22 times as heavy as hydrogen. Its specific gravity is 1·524. It lodges near the floor of places in which it is evolved, when little more than mutual diffusion is going on, owing to its great density; and it may be poured, almost like water, from one vessel to another. Many accidents have happened during the sinking of pits and wells through this gas pouring in and collecting at the bottom, in the absence of air-currents to assist natural diffusion. It is the only gas, except nitrogen, which is evolved by most bituminous coals, and when it is given off in quantity active ventilation is required in order to carry it off, so as to keep the atmosphere sufficiently pure to work in.

Carbonic acid has long been regarded as possessing poisonous properties, more particularly in consequence of the many deaths which have resulted from the burning of charcoal and carbonaceous material in rooms where there was a deficiency ventilation, and by reason of the fatal nature of th after-damp of explosions in coal mines—the deleterious effects being attributed to the presence of thi gas. Leblanc, who carried out a great number o experiments upon dogs, which were confined in an air-tight compartment and compelled to breathe an atmosphere containing the products of the combustion of charcoal, found that the fatal effects of such products were due, principally, to the presence of carbonic oxide, and that an animal could live without any sensible inconvenience in an atmosphere containing a very appreciable percentage of carbonic acid. As an instance, Leblanc in one of his experiments shut up a dog for three-quarters of an hour, and the animal was compelled, during this period, to breathe in an atmosphere containing at the expiration of the time no less than 30 per cent. of carbonic acid, and yet the dog survived.

We have already noticed that the density of carbonic acid is very great, and the baneful effects produced by this gas, over and above those of the recognised non-poisonous gases, are, in a great measure, due to its superior density. It is urged that on no account should the percentage of carbonic acid present in the atmosphere of any habitation, room, or any other place—coal mines not excepted—exceed more than 5 parts in 1,000 parts of air. This is allowing more than ten times the normal quantity usually present in the atmosphere of country districts.

Although air varies but slightly, so far as its component gases are concerned, it has been recently shown by Dr. Angus Smith that the organic putrescent matters in it vary considerably, and are to be found in much larger quantity in the air of towns than in the country, and especially in the atmosphere immediately above organic matters in a state of decomposition. Doubtless the carbonic acid was also higher than in the country districts, and almost in the same ratio as the organic matters.

If, as Leblanc and many other chemists affirm, air containing more than 5 parts in 1,000 is injurious to breathe—an assertion which we do not attempt to disprove—some constituent other than carbonic acid must be looked for, in order to account for the ill effects produced by inhaling such an atmosphere. We do not for a moment lose sight of the absolute necessity of ventilation and of pure air, nor do we hesitate to say that, should the atmosphere in any habitation, hospital, or room, contain more than 5 parts per 1,000 of carbonic acid, that it must be unfit for breathing, and likely to cause ill effects through the long-continued inhaling of the same; but, on the other hand, we do not consider that the ill effects, from whatever source they may arise, are due to the presence of carbonic acid; and we believe that when this gas is present in air without being accompanied by decomposing organic impurities and putrescent animal matters to the extent of ½ per cent., no inconvenience is felt therefrom. If the presence of this gas is so deleterious as it is supposed to be, how is it then that the many individuals who nightly sleep with their heads completely buried under the bedclothes, in such a position that diffusion must take place with slowness, seldom suffer to any perceptible extent, and rarely, indeed, do we hear of fatal accidents arising from this cause. There are thousands, who comprise not only children but also a large number of adults, who always practise this unhealthy habit through the influence of weak nerves or fright. It is only necessary, too, to take into consideration the gases evolved in mines, and to determine the percentage of carbonic acid which is present, in order to satisfy ourselves that air containing much more than 5 parts in 1,000 is respirable, and that ½ per cent. is not deleterious, provided it does not arise from the breathing of animals.

Many instances have come under the author's notice where men have continued working day after day for months in a new seam or new heading into virgin ground, in an atmosphere containing more than 1 per cent. of carbonic acid in addition to 5 per cent. of marsh-gas, and they have not experienced any ill results, remarking only that the air was rather heavy, by reason of which they were allowed one hour each day.

In levels and seams of semi-bituminous and bituminous coals in South Wales, in part or whole worked to the dip, with scanty ventilation in some particular spots, perhaps, through the non-completion of air splits or conveyances, men often work in an atmosphere containing from 2 to 5 per cent. of this gas for hours together. There is no doubt that too much importance has been attached to the poisonous qualities of carbonic acid, and it is full time that sanitary reformers should look around them in order to discover the real poison which lurks in the atmosphere of crowded rooms and the habitations of the poor in large cities.

Another point which is worthy of reflection is, that carbonic acid is the product of the oxidation of carbonaceous food in the lungs and blood (see 'Respiration'), and the air ejected from the lungs contains from 3 to 6 per cent. according to circumstances. In the act of expiration, and immediately before inspiration, or taking in breath, the lungs are, to a certain extent, filled with air, or rather air, carbonic acid, and an excess of nitrogen, together with small quantities of organic matters. Now it is evident that when air is breathed into the lungs, the gaseous contents of the air-tubes and lungs will diffuse through and mix with the fresh air inhaled, independent of the process of false diffusion by which carbonic acid is rejected, and no small quantity of that gas finds its way back again. Under these circumstances it can hardly be expected that nature should have endowed carbonic acid with active poisonous qualities. It may be said of the organic matters which are evolved from the lungs, that they are to some extent re-inspired, in the same manner as carbonic acid; this is, doubtless, the case. (See pp. 263 and 266.)

The readiness with which carbonic acid can be determined either in the air or in a gaseous mixture, renders it peculiarly adapted as a test for the state of the atmosphere in the wards of hospitals, and in narrow courts, alleys, &c., where contagion exists. Under these conditions, the quantity of carbonic acid may be regarded as a measure of the pollution of air by breathing (except open air cases), but this would not hold good in the galleries or headings of a coal-mine, owing to the quantity of carbonic acid which is evolved from the coal and shale, and which is, as we have previously observed, often very considerable.

Carbonic acid is prepared, for the purpose of experiment, by treating chalk, marble, or limestone, with hydrochloric acid (spirits of salts), in any convenient flask provided with a bent tube, which passes through a cork in the mouth of the flask. It is, as we have seen, very soluble in water, but it may be collected over warm water, in which it is less soluble than in cold. The density of carbonic acid being so great, the gas can be collected by displacement, and for this purpose the delivery tube should reach nearly to the bottom of the vessel in which it is intended to be collected. When the collecting vessel is full of carbonic acid, a lighted taper or match will be instantly extinguished when placed just below the mouth. The usual test for the presence of this gas is to add a little clear lime-water and shake the vessel containing the gas, when a white, finely-divided precipitate of chalk, or carbonate of lime, will be formed. If to a tube of this gas collected and standing over mercury, a few drops of caustic potash be added, the mercury will rise and occupy the whole tube, provided it does not exceed 28 inches in length. To determine the quantity of carbonic acid in a gaseous mixture, it is only necessary to introduce a portion of the mixture into a graduated tube of known volume, and me[illegible]t carefully, recording the temperature [illegible] the barometer, then absorb[illegible] caustic potash and measure again, taking the same precautions as to temperature and barometer. The loss in volume, multiplied by 100 and divided by the number of volumes taken, after correcting for temperature, &c., will give the percentage of carbonic acid present.

When the percentage of carbonic acid is very small, as it is in the atmosphere, and generally in the return air of mines, it is necessary to use a very large volume of air, in order to accurately determine the quantity of gas present—a much larger volume, in fact, than could be manipulated in a tube. In this case several litres, or one or two cubic feet of the air, are first passed over granulated chloride of calcium to dry it, and then through a U-shaped tube containing soda lime,[1] slightly moistened, and accurately weighed, or through Liebig potash bulbs partly filled with caustic potash (S.G. 1·27). The bulbs with their contents, or the U-tube containing the soda lime, must be weighed, and after the required volume of air has been drawn through, by the aid of a respirator, they are again weighed, the difference between the two weighings gives the weight of carbonic acid present in the volume employed. A large volume of air must be used if the apparatus at command is not very delicate, and the operation conducted with great care.

Every colliery should have some arrangement whereby the quantity of carbonic acid in the return air (near to the bottom of the upcast shaft) could be determined. A dry gas meter, which has been accurately adjusted, could be placed in a recess in the side of the return air-gallery within a short distance of the upcast. The meter is connected with a flask provided with an indiarubber stopper pierced with two holes, through which two glass tubes pass; that tube connected with the meter reaches nearly to the bottom of the flask, while the other leading from the flask simply passes through the indiarubber stopper, and is joined to a small fan worked by the force of the air-current, which draws the air through the meter and thence through the flask, which is partly filled with a solution of hydrate of barium or hydrate of lime (lime water). When the required number of feet has passed through, the contents of the flask, now white and turbid from the carbonate of barium or carbonate of lime formed, are filtered, and the white compound washed with distilled water (as quickly as possible), dried and weighed, and the quantity of carbonic acid calculated from the weight of the carbonate found. Thus, if hydrate of barium was employed, then $\frac{44}{153}$ of the precipitate will be carbonic acid, and if lime-water was used, then $\frac{44}{100}$ of the compound weighed will be carbonic acid.

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[1] Soda lime is prepared by slaking quick-lime with a dilute solution of caustic soda (sodium hydrate) and then dried.

It would be out of the limits of this treatise to deal further upon this matter, important as it is, but it may be mentioned that a very neat way of conducting the analysis is (where a Sprengel pump is at hand) to pass the air through a specially constructed apparatus holding the hydrate of barium, and then simply connect from the meter and join to the Sprengel pump, the apparatus being so arranged that sulphuric acid [illegible] on the carbonate of barium in the [illegible]atus as soon as a vacuum [illegible]he Sprengel. The

Sprengel pump (named after the inventor) is an arrangement in which mercury is caused to fall down a long glass capillary tube that is in connection with any vessel in which it is required to produce a diminution of pressure or a vacuum. Each drop or pellet of the liquid metal as it falls imprisons a small quantity of air, and the long column of mercury more than counterbalances the outward pressure of the atmosphere, so that after a time, according to the size of the vessel to be exhausted, the continual falling of the mercury determines the removal of all but the minutest trace of air or gas present.

We are not acquainted with any colliery possessing the meter arrangement alluded to, but such an instrument with its appurtenances would be valuable in the hands of the well-trained managers of collieries of the present day.

The aspirator made by Danger, of Manchester, is well adapted for drawing a measured quantity of air through any absorbent, and it has also the advantage of not being cumbersome; the same quantity of water being used over and over again by merely inverting the apparatus. The bottles constituting the arrangement are graduated for aspirating known volumes, and registering the same.

Carbonic acid is a colourless gas, and inodourless when pure, but possesses a slightly acid taste. It reddens blue litmus, but not permanently, as it assumes its original blue colour on exposure to the atmosphere. Carbonic acid does not support the combustion of substances generally; on the contrary it greatly retards the combustion of bodies which burn in oxygen, but it is decomposed by potassium and magnesium, at a red heat, with the formation of the oxide of the metal, and carbon is deposited. Iron, zinc, hydrogen, and charcoal, at a red heat, abstract half the oxygen, and convert it into carbonic oxide.

The great mass of living plants on the surface of the globe subsist upon the carbonic acid which the atmosphere contains, and in the process of assimilating the carbon, the plant, under the influence of sunlight, sets oxygen free. It may be liquefied by the application of great pressure or intense cold, and subsequently rendered solid. Faraday, who succeeded in liquefying all but six of the known gases, found that when carbonic acid was subjected to a pressure of 36 atmospheres at 32° F., it became liquefied. All liquids on passing into the gaseous condition take up a considerable quantity of heat; when, therefore, a jet of liquid carbonic acid is allowed to escape into the atmosphere, the first portion of the liquid on instantly assuming the gaseous state, robs so much heat from the remainder, that much of the liquid becomes frozen. A copper box, in which the liquid is more exposed to the cooling action of itself, affords a convenient receptacle for the accumulation of the solid carbonic acid, which resembles snow.

Faraday found that extremely low temperatures could be obtained by treating the white, snow-like, solid carbonic acid with ether, especially *in vacuo*, and he succeeded in producing a temperature so low that alcohol is rendered pasty, and all the gases except oxygen, nitrogen, hydrogen, marsh-gas, carbonic oxide, and ni[illegible], are liquefied under a pressure of [illegible] when exposed to the intense [illegible]

Carbonic Oxide.

Symbol CO. Molecular weight 28.

1 litre of the gas at 0° C. and bar. 760 mm., or 30 in., weighs 1·2544 gramme.

1,000 cubic feet of the gas at 32° F., and bar. 30 in., weighs 78·305 lbs.

Carbonic oxide has never been detected in the atmosphere, and until recently it was not known to be produced by any natural process. Dr. Meyer, when determining the gases in a German coal which had been weathered, found 1·82 per cent. of carbonic oxide in the enclosed gases after the coal had been exposed to the atmosphere for one week, and in the same coal no carbonic oxide was found previously or afterwards.

Carbonic oxide is not produced from carboniferous coals at 500° F., and the volume recorded by Dr. Meyer stands alone. Recently, however, Zitowitsch and the author have found that this gas is present in lignite in appreciable quantity; and this is a somewhat curious coincidence, as it is not usually generated during the putrefaction or decay of vegetable matters.

Incandescent carbon reduces carbonic acid to carbonic oxide, and, in blast furnaces, the fuel at the lower portions near the *tuyeres* receives the blast, and the carbon of the fuel is momentarily converted into carbonic acid, but on ascending through the intensely heated mass one atom of the oxygen is removed by the red-hot carbon, and two volumes of carbonic oxide are formed thus:—

$$CO_2 + C = 2CO$$

If the carbonic oxide encounters a fresh supply of oxygen at a sufficiently elevated temperature, it is again converted into carbonic acid, and burns with a blue flame in the same manner as it does on the surface of a fire. It is formed during the destructive distillation of coal, and coal gas contains from 5 to 8 per cent. of carbonic oxide. When steam is passed over red-hot coke or charcoal, carbonic oxide is formed; in fact, in all instances where carbon undergoes oxidation at a high temperature in the absence of sufficient oxygen for complete combustion, this gas is generated.

Carbonic oxide was never supposed to be present in a coal mine, except in minute quantity formed during the combustion of gunpowder or from coke or charcoal fires. From experiments made by the author, the correctness of which have been certified by Dr. Meyer, it was found that during every explosion large quantities of this gas are formed, and that the fatal effects of the after-damp are, in great measure, due to its presence. During the combustion of every explosive mixture containing marsh-gas in which the proportion of air is less than 9·5 parts, carbonic oxide is always formed in greater or lesser quantity, according to the proportion of air present (see p. 323, Appendix).

When oxalic acid, or formic acid, is heated with concentrated sulphuric acid, carbonic acid, carbonic oxide and water are formed in the first instance, and carbonic oxide and [illegible] from the formic acid. Yellow ferrocyan[illegible]ssium (prussiate of potash) carefully [illegible]lphuric acid also yields carbonic [illegible]urpose of experiment it may be prepared from one of the above salts. A little oxalic acid is placed in a glass flask arranged with a bent tube, and connected with another flask containing potash, or a U-tube containing soda-lime for the purpose of removing the carbonic acid. Sulphuric acid (concentrated) is then poured on the oxalic acid in the flask, and heat applied, when carbonic oxide will be given off, and may be collected in tubes over water or mercury. Another method of preparing it, but which requires some little care, is from the ferrocyanide of potassium. This salt is heated with strong sulphuric acid in a flask as before, but no washing arrangement is necessary. Heat is carefully applied until the mixture is liquefied completely, and the temperature is not allowed to rise higher; the gas which comes off is nearly pure carbonic oxide, and may be collected over water or mercury as before.

We have already noticed (p. 152) that iron will, at a red heat, abstract one-half of the oxygen from carbonic acid, and reduce it to carbonic oxide—the iron itself undergoing oxidation. If, however, oxide of iron be heated to redness in a current of carbonic oxide, carbonic acid will be formed, and the oxide of iron reduced to metal. These facts show the affinity of carbonic oxide for another atom of oxygen in order to form carbonic acid, and carbonic oxide, together with hydrogen, exercises this combining affinity in the blast furnace to the ultimate reduction of the oxide of iron to metal. The blast furnace gases, according to Bunsen, contain about 30 per cent. of carbonic oxide.

Carbonic oxide is an inodourless and colourless gas, incapable of supporting combustion. It is combustible, taking up one atom of oxygen to form carbonic acid. It possesses exceedingly poisonous qualities, acting powerfully on the blood and nervous system. It forms a compound with the hæmoglobin of the blood, which is with difficulty broken up by oxygen; the inhalation of a very small quantity produces a most unpleasant sensation, resulting quickly in a painful headache and disinclination to move, followed by prostration and inactivity, and, if continued to be breathed, asphyxia follows, and death soon results. Air containing only ½ per cent. of this gas would, from prolonged breathing, produce fatal consequences.

According to Dr. Letheby, air containing ·5 per cent. of this gas killed small birds in three minutes, and in half that time when 1·5 per cent. was present. Dr. Hoppe-Seyler found that animals which had been compelled to breathe carbonic oxide were restored by continuing artificial respiration for some time; the gas being converted into carbonic acid by oxidation in the blood. The blood of all animals poisoned by carbonic oxide is of a darker colour than the normal. This is, apparently, due to the difference in colour between carbon-oxyhæmoglobin and oxyhæmoglobin, or, in other words, the union of carbonic oxide with the hæmoglobin of the blood, and the deoxidation of the latter, produce the dark colour.

The experiments of Dr. Hoppe-Seyler are so conclusive as to admit of some valuable deductions being drawn from them. [illegible]s of poisoning by carbonic oxide, woul[illegible] dvisable to carry out Dr. Hoppe-S[illegible] in reference to the many u[illegible] have not fallen victims to the effects of the fire, in addition to the products of the combustion of an explosive mixture, in order to ascertain the result of inducing artificial breathing upon those asphyxiated? It is a question too whether those brave fellows who so frequently fall prostrated by the effects of the after-damp while searching for their ill-fated comrades, would not be better resuscitated by inducing respiration by artificial means, than by the administration of alcoholic stimulants, which is so frequently done.

The author has before suggested in the public press the use of oxygen in cases of poisoning by the after-damp of explosion, and great relief was experienced by the inhalation of that gas in an instance in which carbonic oxide was accidentally breathed in a somewhat concentrated form.

M. Leblanc and M. Tourdes have made interesting and valuable experiments upon carbonic oxide, but we have already quoted so much that it is unnecessary to enlarge upon it.

Carbonic oxide is a narcotic poison. When it is breathed in a concentrated form, such as would be inspired by some of the victims of an explosion, no pain would be felt—the body passing instantly into a state of coma, and whatever position the victim lay, sat, or stood in, in that position he would be found, dead, unless moved by the force of the explosion. Many poor fellows have been found sitting, or leaning, as the case may be, entirely uninjured by the fire or force of the explosion, their countenances, apparently, wearing the expression of life. These are most probably the unfortunate miners who worked near the end of that portion of the explosive mixture in which less than sufficient air for complete combustion was mixed with the marsh-gas, and where, in consequence, the largest proportion of carbonic oxide was generated. It may be urged that the carbonic acid formed during an explosion, and the nitrogen left, would be sufficient to account for the fatal effects of the after-damp; they would in many instances; but in those—and they are numerous—in which persons descending pits after explosions have succumbed to the effects of after-damp when the lamps they carried burned well, the presence of carbonic acid and nitrogen will not account for the results.

Several accidents, many of a fatal nature, have occurred through impeded ventilation, and the mixing of furnace-gases with the air in the galleries, and also through the products of the combustion of coal finding their way into working places. The fatal accidents have, doubtless, happened in consequence of carbonic oxide being present in the gases inhaled.

An atmosphere containing 10 per cent. of carbonic acid will not support the combustion of carbonaceous bodies, but men have been known to live for some time in such an atmosphere, and, as it is improbable that a man would die in an atmosphere containing carbonic acid in which a candle would burn well, the fatal effects which have happened under the circumstances enumerated were, unquestionably, due to carbonic oxide.

The composition of carbonic oxide is:—

	By Weight	By Volume
Carbon	42·86	1
Oxygen	57·14	1
	100·00	2 volumes combined

The specific gravity of carbonic oxide is 0·968. When mixed with half its volume of oxygen and exploded, carbonic acid is formed. Carbonic oxide is absorbed by a hydrochloric acid solution of cuprous chloride, or by this solution neutralised or rendered alkaline with ammonia, and in order to detect the presence of this gas in a compound mixture, the ammoniacal cuprous chloride or acid cuprous chloride is used. Carbonic oxide is sparingly soluble in water; according to Bunsen, water dissolves 1-40th part of its volume at 15° C. (59° F.) This gas combines directly with chlorine, forming carbon oxychloride.

CHAPTER VII.

COMPOUNDS OF CARBON WITH HYDROGEN.

PARAFFINS—MARSH-GAS—ACETYLENE—OLEFIANT GAS —HYDRIDE OF ETHYL—HYDRIDE OF PROPYL—QUARTANE.

Paraffins.

ALL the compounds of carbon with hydrogen are inflammable, more especially the gaseous and liquid compounds which have been grouped together under the head of *hydro-carbons.* So far, our knowledge of the solid hydro-carbons in coal is very incomplete, owing to the difficulty of separating them from the finely-divided carbon without determining their decomposition or resolution into other compounds. From the paper in the Appendix 'On the Gases enclosed in Cannel Coal and Jet,' it will be seen that those coals contain, in addition to gaseous hydro-carbons, some oily matters which are given off *in vacuo* at the temperature of boiling water. These oily matters are not present in sufficient quantity to determine their nature, in experiments such as those to which the coals were subjected, but it appears very probable that many of the coals contain oily matters belonging to the paraffin series of hydro-carbons—a series in which the carbon atoms are united to twice their number of hydrogen atoms and two more atoms added. They are represented symbolically thus: C_nH_{2n+2}; and if the value of the carbon is 3, then the compound will be C_3H_8, or twice as many atoms of hydrogen as carbon, and two more atoms of hydrogen added.

The true anthracite, and most of the so-called steam coals, do not appear to contain these liquid hydro-carbons; but whether they have been eliminated during the process of the coal formation, is a matter open to conjecture. One point is decided—the more hydrogen a coal contains, the greater the quantity of heavy hydro-carbon gases and oily matters which it holds ready formed.

Of late years the discovery of petroleum in America has led to its introduction into this country, and to its being used in immense quantity for illuminating and other purposes. Prior to this, the Boghead cannel was found to be capable of producing solid and liquid paraffins in remunerative quantity, and from then until now it is worked and distilled for the purpose. The finer kinds of liquid paraffin are used for mixing with vegetable and animal oils for lubricating purposes, and the solid paraffin is made into candles. More recently the Leeswood cannel, of Mold, Flintshire, has been distilled with almost equal success to that of Boghead cannel, and it might be employed in the manufacture of liquid and solid paraffin. It appears very probable that the paraffins are condensed in the pores of the cannel, ready formed, and can be obtained from it by simply heating the coal to a temperature slightly above the boiling point of the required paraffin. In some of the author's experiments Scotch cannel was roughly subjected to temperatures varying from 130° to 570° F., and liquid products were obtained which were found to contain paraffin.

The temperature at which Boghead and Leeswood cannel and various cannel shales used for oil-making are distilled, is a barely visible red heat. At this temperature, probably the most dense and solid paraffins in the cannel or shale are broken up into two or more bodies of the same series, and so add to the actual yield of oil. If the temperature is allowed to rise to a visible red heat, dissociation of the solid paraffin into liquid bodies takes place, and the yield of solid paraffin is very considerably reduced. Much care is necessary in regulating the temperature in order to obtain the maximum quantity of the more valuable products.

The immense quantity of petroleum obtained native in various parts of the globe has been the means of extending the use of mineral oil for illuminating purposes. In America some of the petroleum rises to the surface, forming wells or springs, while in other, and now the majority of instances, it is obtained by boring deeply in such places as give indications of its abounding beneath. The crude oil is then pumped out, and the gases and volatile liquid portion separated by distillation. The petroleum from America, and also that obtained from some other sources, evolves all the gases of the marsh-gas series, from [illegible]h-gas up to the liquid compounds of the sa[illegible] Petroleum also contains other heav[illegible]obably homologues of marsh-[illegible]

We have already observed that the cannel coals, as also some bituminous coals other than cannel, contain, ready formed within their pores or interstices, oily vapours and matters possessing all the characters and smell of petroleum, and, moreover, these coals actually occlude the gases which are found in petroleum strata and petroleum springs. The gases of the C_nH_{2n+2} series, or paraffin series, are marsh-gas, CH_4, hydride of ethyl, C_2H_6, hydride of propyl, C_3H_8, and quartane, C_4H_{10}.

It has been a matter of much speculation as to how petroleum has been produced, and various theories have been adduced to account for its existence. It has been suggested that petroleum was formed by the union of carbon and hydrogen at high temperatures and at great depth below the earth's surface, under the influence of pressure and volcanic action, or by the action of water on carbonaceous matters under certain conditions. Reichenbach formed the opinion—based, however, upon some erroneous conclusions, as to the absence of petroleum in the products of the destructive distillation of carbonaceous material—that petroleum was formed in the ordinary process of the conversion of organic matter into coal, and not formed by destructive distillation at all.

Petroleum is present in more or less quantity in all the distillation products of gas making, no matter from what coal the gas has been made, and hence the generally accepted theory that it has been generated by the action of heat upon coal at great depths from the surface. The most fatal objection, perhaps, which can be urged against the latter conclusion is the fact that anthracite coals—which contain the least hydrogen—do not present such appearances as would justify one in asserting that this class of coal had been carbonised, or subjected to a temperature anything like that approaching redness. Some of the true anthracite coals are so hard and dense that they show conclusively, from their structure, that they have been at some period of their existence under the influence of great pressure, but they do not show any indications of having undergone a process of carbonisation, or of having suffered from any excessive heat.

Steam coals, many of which approach very near to the anthracite in respect to the percentage of hydrogen, are very porous and friable, and bear no evidence of great pressure or of heat. Some of the cannel coal, for instance, that from the Wigan Arley mine (page 355, Appendix) bore neither marks of great pressure or of intense heat, and yet it contains the gases of the paraffin series, and some oily matters having the odour of petroleum can easily be obtained from it at a temperature not much above that of boiling water. Again, the fact that petroleum is a product of the destructive distillation of coal is not sufficient evidence to prove that it did not exist ready formed in the coal itself, and the conclusion that it has been formed from carbonaceous material under the influence of pressure, and at a temperature very materially below the point of destructive distillation, seems equally as feasible as the destructive distillation hypothesis. As far as our present knowledge extends, it would be nothing more than conjecture to bring forward any hypothesis having as its aim the solution of the problem as to the process which has been at work in the production of native petroleum.

Petroleum oils occur in the greatest abundance in North America, Burmah, West Indies, and Persia, and in lesser quantity in almost every country in Europe which is in the temperate zone. The oils known as solar oil, rock oil, photogene, and upione, are all paraffins.

Marsh-Gas.

Light Carburetted Hydrogen—Hydride of Methyl—Proto-carburetted Hydrogen, or Fire-damp.

Symbol CH_4. Molecular weight 16.

1 litre of gas at 0° C. and bar. 760 mm. (30 in.) weighs ·717 gramme.

1,000 cubic feet of gas at 32° F. and bar. 30 in. weigh 44·665 lbs.

The density of marsh-gas compared with hydrogen is 8. The specific gravity is 0·5576.

Marsh gas is the lightest of all hydro-carbons, and hence the reason it was long known as light carburetted hydrogen. The name marsh-gas was given on account of the fact that marshy and boggy lands, and stagnant and muddy pools containing organic matter in a state of decomposition, are constantly evolving it. In the bottom of muddy pools, this gas, together with nitrogen and carbonic acid, is held between the slimy matter, and if the pool be stirred, it may be collected in some quantity. Peat bogs evolve this gas mixed with more or less carbonic acid and nitrogen. Coal-gas contains about 38 per cent. of marsh-gas, and it is invariably a constituent of the gases formed during the destructive distillation

of carbonaceous material containing hydrogen. In America, Italy, Persia, and other countries it is found escaping from the earth in large volume, fed, most probably, from seams of coal beneath. In Great Britain it is frequently found escaping from fissures in rocks and subterranean channels in connection with beds of coal. This gas constitutes the greatest portion of the fire-damp of the miner, and it is, when mixed with air and ignited, the cause of the fatal explosions which happen in coal mines. When this
gas is evolved in the shape of 'b
usually about 96 per cent. of th
page 352, Appendix.) Blowe
enormous dimensions, and so g
which they are in connection,
some mines have at intervals b
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surface, which, in some instanc
evolve gas with no apparent di
while other blowers are depend

165-6

the atmosphere. When the barometer is high scarcely any gas escapes; and when the barometer is low it escapes in appreciable quantity, affording a very conclusive proof of atmospheric influence upon the escape of gas. Marsh-gas is evolved in the blast furnace gases, and in the coking of coal.

It can be prepared, for the purpose of experiment, in an almost pure state by heating a mixture of acetate of soda, potash, and lime in a retort, and collecting the gases evolved over water. The proportions are acetate of soda 2 parts, caustic potash 2 parts, quick lime 3 parts. The quick lime is added to prevent the potash perforating the retort, which s most conveniently made of glass; a Florence oil-flask will answer the purpose. When absolutely pure marsh-gas is required, it may be obtained by decomposing zinc-methyl with water, or iodide of methyl, or anhydrous chloroform, with the copper-zinc couple. The copper-zinc couple consists of zinc foil upon which black spongy copper has been deposited, and is made thus:—Zinc foil is cut in small pieces and placed in a flask and covered with a solution of sulphate of copper in water. The copper is rapidly deposited on the zinc, an equivalent quantity of the latter metal entering into solution in the water in combination with the sulphuric acid. When the solution becomes colourless it is renewed, and this is repeated until sufficient copper is deposited on the zinc, and then the 'couple,' as it is termed, is thoroughly washed with water and afterwards with absolute alcohol when required dry. The researches of Gladstone and Tribe, who devised this copper-zinc arrangement, have shown that it is capable of exercising a feeble, but definite electrolytic action upon many chemical compounds. The average composition of fire-damp as taken from the working face of coal is—

Marsh-gas	96·0
Carbonic acid	·5
Nitrogen	3·5
	100·0

It will be seen, therefore, that it is far from being pure marsh-gas; some of the blower gases contain, in fact, as much as 3 per cent. of carbonic acid. From 99·5 to 99·8 per cent. of the gas made from acetate of soda and potash consists of marsh-gas.

Marsh-gas is frequently called hydrogen by firemen and overmen in collieries, owing probably to force of habit in calling marsh-gas light carburetted hydrogen, and to their belief in the propriety of shortening the name to the last word, or, it may be, owing to their non-acquaintance with the existence of the gas hydrogen, or from having no desire to extend their chemical knowledge.

Marsh-gas is the richest in hydrogen of all the hydro-carbons. Its composition is—

	By Weight	By Volume
Carbon	75·0	1
Hydrogen	25·0	4
	100·0	2 volumes condensed.

It consists of 5 atoms—1 of carbon and 4 atoms of hydrogen, which close together, when they combine, into the space of two atoms. It does not support combustion, but is very inflammable. It is tasteless and inodourless, and possesses very neutral properties, and does not readily combine with any element. With chlorine it does not combine immediately even under the influence of direct sunlight, but after a time combination takes place attended with explosion. It is one of the permanent gases, and has only recently been liquefied under the greatest pressure, combined with the most intense cold. (See page 69.)

100 volumes of water at 59° F. (15° C.) dissolve 3·9 volumes of marsh-gas; 100 volumes of alcohol dissolve 48·2 volumes at the same temperature. It is indifferent to the action of all acids, and in fact is not acted upon at all, except by chlorine. It will be seen therefore that the fertile ideas brought before the public, aiming at the removal of fire-damp from mines by converting it into some innocuous and uninflammable compound, are not likely to succeed in this direction. It is practically impossible to remove marsh-gas from a gaseous mixture, even on a small scale, by the chemist; how much more impossible must it be, therefore, to remove the immense volumes of gas which are constantly evolved from the working face of coal, and cracks in the rock, in coal-mines.

Marsh-gas in the presence of air is oxidised by spongy platinum and platinum black, or by platinised charcoal; but it is scarcely worth remarking that these would not be available for destroying the fire-damp in mines. The finely-divided platinum, or platinised charcoal, do not undergo any change, but simply determine the combination of the oxygen of the air with the marsh-gas, and convert it into carbonic acid and water. The products of the oxidation of marsh-gas would vitiate the air-current to such an extent as to cause more injury than the marsh-gas itself. Chlorine, in the presence of moisture, converts marsh-gas into carbonic acid and carbonic oxide, with the formation of hydrochloric acid.

Marsh-gas is partially decomposed by the electric spark, but never completely. At a white heat, marsh-gas is broken up into carbon and free hydrogen. It does not possess poisonous qualities; in fact, it is surprising what a large quantity can be present in air without causing any material inconvenience to persons breathing it. It is not at all improbable that some of this gas may become oxidised in the blood, and used up as fuel to sustain animal heat.

Sir H. Davy—the illustrious chemist who originated the safety-lamp—was the first who made experiments on this gas in order to determine its explosive limits. He found that when it was mixed with 3·5 times its volume of air it does not explode, but burns quietly in contact with the atmosphere; with 5·5 volumes of air it explodes slightly, the flame passing somewhat tardily through the mixture; and that with 8 or 9 volumes of air the force of the explosion was greatest. The author found that the force of the explosion was greatest when air is mixed with marsh-gas in the proportion for complete combustion, viz. 9·5 parts of air to 1 part of marsh-gas. Davy found also that 1 part of marsh-gas mixed with 14 parts of air was explosive. The marsh-gas which he employed was nearly pure, and consequently his determination of the explosive limit would be slightly higher than that he would have obtained with fire-damp, but this does not much affect the result. In fact, the explosive limit at the ordinary temperature and pressure of the atmosphere is dependent upon the volume of the mixture, the cooling surface to which it is exposed, the temperature of the mixture and that of the igniting body. For instance, in a glass tube ½ an inch in diameter a mixture of 1 part of marsh-gas with 12 parts of air will not explode, nor will a mixture of 1 part of marsh-gas and 13 parts of air explode in a tube ¾ of an inch in diameter; but the author found that marsh-gas mixed with 16 volumes of air will take fire and burn, but so quietly as to be scarcely called an explosion. Mr. Galloway has recently shown that the gas of the Llwynypia blower, before referred to, will ignite when mixed with 15 volumes of air.

As before observed, much depends upon the bulk of the explosive mixture and the temperature of the flame. In a narrow tube gases are exposed to so much cooling surface that the temperature does not rise high enough to allow a weak explosive mixture to burn when a light is applied:—again, if in a wider tube an electric spark is passed—intensely hot though it may be—its heating influence does not extend far enough to rise the temperature of the gas some little distance beyond, but if a candle is taken into a weak explosive mixture, every facility is offered to start the combustion, while the gases at the moment they are ignited may meet with a more concentrated portion and so gather strength.

A very important consideration respecting the explosive limit of a mixture of marsh-gas and air, was elicited by the author during his investigation into the nature of the gases in South Wales coals.

It was found that when a mixture of air and marsh-gas would not explode under the ordinary pressure of the atmosphere, that it became explosive by increasing the pressure. An instrument was devised for the purpose of carrying out some experiments on marsh-gas in order to ascertain its explosive limit with air under pressures varying from 1 to 20 atmospheres, when it was found that the limit varied with the pressure and the diameter of the tube in which the experiments were conducted. Through the pressure of other work the experiments have not been completed, another apparatus having been constructed only recently, it being found necessary to enlarge the explosion tube very considerably. The author hoped, however, to be enabled to publish very shortly some interesting experiments in this direction.

The effect of pressure on explosive mixtures, more especially that of air and marsh-gas in a mine, will be more clearly seen when considering the results incidental to the ignition of an explosive mixture, see page 228, but, although it is impossible that a mixture of marsh-gas with more than 16 parts of air will become ignited in a mine by a naked light, it is quite possible that a mixture of 1 part marsh-gas and 20 parts of air will take part in an explosion which has been started by a more concentrated mixture, owing to the great pressure produced by the intense heat, and the secondary heat which results as the product of the power expended.

Sir H. Davy tried the effect of nitrogen and carbonic acid [illegible] various proportions with an explosi[illegible] ntaining marsh-gas, and found [illegible] ic acid added to 7 parts of an explosive mixture caused it to be non-explosive, and that 1 part of nitrogen added to 6 parts of the mixture exercised a like influence.

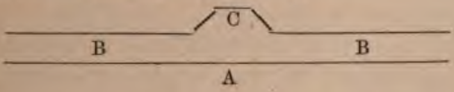
The gas evolved from coal of a semi-bituminous nature (*i.e.* coal intermediate in character between steam and bituminous) contains a larger percentage of carbonic acid and nitrogen than that from steam coal; and these gases prevent, in no small degree, the ignition of a mixture of fire-damp and air. But accumulations of marsh-gas do not often occur in mines when such coal is worked, and, when it does, the explosion is rarely attended with serious results, because coal belonging to the bituminous class, in the North of England and South Wales coal-fields, does not contain, as a rule, 1-5th the quantity of gas which steam coals do.

The average constitution of the blower gases from steam coal, shows the presence of ·5 per cent. of carbonic acid, or 1-200th part the volume of gas. The explosive mixture employed by Sir H. Davy to determine the effect of carbonic acid upon it, consisted of about ·75 of a part of marsh-gas, and 6·25 parts of air, in all 7 parts, and to these 7 parts, 1 part of carbonic acid was added; the result being that the mixture was rendered inexplosive: but 1 part of carbonic acid to 7 parts of this mixture would represent many hundred times as much carbonic acid as would be present in an explosive mixture derived from the fire-damp. In some of the blowers from steam coals of the anthracite class, nitrogen and carbonic acid are found in some quantity, and their presence in an explosive mixture considerably modifies the result.

Fire-damp burns with an almost non-luminous flame, and, in fact, the flame of pure marsh-gas is practically non-luminous. When, however, a small quantity of hydrocarbon vapour, or coal-dust, is mixed with it, as is usually the case with that evolved from blowers, or the working face of coal, or from cracks in the rocks contiguous thereto, it is somewhat luminous—a luminosity always characterised by the peculiar yellowness of the flame. The presence of 1 per cent. of hydride of ethyl in the blower gas of Llwynypia adds very considerably to the illuminating power of the gas.

The character of marsh-gas with regard to its collecting and lodging near the roof of the galleries, &c., in coal mines, which we inferred on page 76, may be conveniently considered here. Marsh-gas or fire-damp (we retain the name for simplicity sake) is often found in more or less quantity occupying the open portions originally filled with rock, which has been removed by blasting, as in the case of thin seams of coal, or by the cracking and subsequent falling of the rock itself, either through the crushing force of the mass above, or other cause. After the coal has been worked from under the top, the latter gradually subsides, in spite of its being supported, however effectually, by timber. It is well to carefully remember this fact, not that there is anything new about it, but because of its being too well known it is apt to be forgotten. In the act of lowering, a partial disintegration occurs, to what extent will depend upon the nature of the material. The 'top' of galleries or headings naturally suffer, and falls of rock are of fre[illegible]e. In the recesses so formed, and in those formed by packing slag and rubbish, fire-damp is frequently found when a safety lamp is raised or admitted into the cavity, especially if these recesses are not very far removed from the 'working face,' and accumulations of gas are found, in point of fact, in these positions, in collieries when the ventilation is practical and efficient. This circumstance has given rise to very erroneous conclusions, which are even at the present time rife in the minds of men possessing not merely practical, but good theoretical knowledge. The light character of marsh-gas has always been acknowledged, and, owing to its low density, it is said to rise upwards and lodge near the roof, and to fill the cavities and other available receptacles, and this takes place during the time the mine is in the act of being worked. When there is a deficiency of ventilation, the fire-damp is said to rise to the upper portion or top of a gallery and there remain, and observations of this kind are recorded in works on mining, and are generally credited by colliery officers. In the same manner carbonic acid is said to lodge on the 'floor' or 'thill.' That marsh-gas is often found in larger quantity near the roof of a gallery than near the thill or floor is not denied for a moment, neither is the fact that carbonic acid is found in greater quantity near the floor or thill of a gallery; but the mere event of finding gas in these positions does not prove that it is *lodged* there, nor is it so. On the contrary, marsh-gas is always diffusing in every direction, and it is only in those places where the gas is evolved in greater quantity than will diffuse or become carried away by ventilation, that any accumulation takes place. We have already st that these erroneous ideas in reference to marsh- arose from the fact that it is found in the crevi and holes, and near the roof in coal mines. T explanation of this is very simple—the mere fact portions of the top rock falling, and of the squeezi in or lowering of the 'top' throughout the who length of the worked portion above the coal, afford a communication with, it may be, some rider or unworked seam of coal above, with the receding working face, or with crevices which are in communication with stores of fire-damp extending to considerable distances. Now the pressure of the atmosphere being the same on all sides, the gas in the fissures and cracks in the top are subjected to that pressure externally, so that air finds no outlet through these cracks, and the diffusion which takes place is simply 'natural' or mutual diffusion. The fire-damp which issues into these cracks and channels meets with the same pressure as it would encounter if evolved direct into the air-current, so that it would find its way downwards by virtue of the extra force or pressure of the imprisoned gas into the top of the holes, goaves, or receptacles in the top rock, and it would be more likely to escape or find an exit in these places, or rather come in contact with the ventilating current here, owing to the fact that more easy communication is afforded by the dislocation and partial disintegration of the top caused by a fall, which would be followed by a partial opening up of the surrounding mass. The fire-damp, therefore, instead of accumulating and lodging at the roof of a gallery by virtue of its lesser density, is forced downwards, until it finds its way into the holes and other receptacles, and is continually fed from above. When marsh-gas or fire-damp escapes upwards from the thill or floor, and makes its appearance in quantity near the top or roof, it shows deficiency of ventilation, or a strong inpour of gas, but if there is any ventilation at all it will be, even then, largely mixed with air.

The reason why fire-damp remains in the form of an explosive mixture in holes in the top is that it is fed from above more quickly than diffusion proceeds—the ventilating current not affecting it to a very great extent. Let the following lines represent a portion of a gallery or heading from



which some of the 'top' has fallen. A is the floor, B, B, the roof, and C the hole caused by the fall. If a lamp be raised about half-way between B and C, an explosive mixture may be encountered, but if the lamp is held near the cracks in the roof B,B, which is the 'top' line of the ventilating current, not a trace of gas will be indicated by it (provided there is efficient ventilation). Gradually stop the ventilating current so that the air travels at a scarcely perceptible rate, and then apply the lamp, the presence of fire-damp issuing from the cracks in the top may be detected. Active ventilation sweeps away all the gas which escapes from cracks in the line of the top rock or roof, but as the current can find no outlet through the hole at C, and encounters a pressure equal, or superior, to that along B, B, it travels onward, heedless, as it were, of any gas or air situated out of the line extending from B to B, and thus it happens that admixture and diffusion does not proceed very rapidly at C. The ventilating current, in passing along the line B, B, rubs against the air or gaseous mixture in the open space in much the same manner as if the top line of the gallery was unbroken, and passes onward without troubling to take a turn round the inside circumference of the hole at C. Admixture and diffusion proceeds with greater rapidity than if it was entirely dependant on mutual diffusive force, and the quantity of gas present in the hole will depend upon the quantity evolved and the velocity of the ventilating current.

If any marsh-gas or fire-damp accumulates near the roof or 'top' line of a gallery or heading, it indicates that the gas is evolved in greater quantity than can be carried off by the ventilation, and in all instances where such an accumulation takes place, there must be either a deficiency of ventilation or an unusual inpour of gas. The ventilating current in the act of approaching the working face of coal, comes in contact with air of lesser density (at a higher temperature), and the heated and lighter gases rising, to a certain extent, above the colder current, carries with them, for a moment, much more marsh-gas than is present in the lower stratum, but as the mine atmosphere moves onward, admixture takes place, and the marsh-gas soon becomes equally distributed throughout the air.

When marsh [illegible] in air it forms carbonic acid and wa[illegible] occupies two volumes, and requires four volumes of oxygen for complete combustion, or twice the actual volume of the marsh-gas. The amount of oxygen required is contained in 9·5 parts of air, and all mixtures of marsh-gas with less than 9½ parts of air are not *completely* burnt, or converted, entirely into carbonic acid and water. Until recently it was believed, as Sir H. Davy says, that when marsh-gas was mixed with less air than is required for complete combustion only as much marsh-gas would be consumed as the oxygen present could convert into carbonic acid and water, and that the excess of marsh-gas would remain in its natural condition. In May 1874 the author, on examining the original works of Sir H. Davy, was led by some of his experiments to investigate this character of marsh-gas. It was found that marsh-gas did not conform to the accepted view, and, that in no instance was the excess of marsh-gas left unaltered when the proportion of air was insufficient for complete combustion, but that marsh-gas was entirely decomposed under these conditions, and carbonic oxide, carbonic acid, water, and free hydrogen are formed.

The experiments on the effect of pressure upon explosive mixtures tend to show that it is impossible, with any degree of certainty, to determine the explosive limit of mixtures of marsh-gas and air, and in the face of a living mass of flame, and under the immense pressure to which the gaseous mixture is subjected during an explosion, there is no telling how dilute a mixture will not explode or at least burn.

The presence of marsh-gas is usually detected by the aid of a Davy lamp. The flame is turned down low, and the lamp placed in the situation where the gas is looked for. When the gas is present in the proportion of 1 part of marsh-gas to 30 parts of air, it is at once detected by the appearance of the flame. The most conclusive experiments upon this point were carried out by Mr. Galloway, Assisting Inspector of Mines, and the results are recorded in the 'Royal Society's Journal,' May 1876, from which we extract the following:—

'The wick of a lamp, having been carefully trimmed, was drawn down until the flame presented the appearance of a small blue hemisphere about $\frac{1}{8}$ inch high and $\frac{1}{4}$ inch diameter at the base, and having a conical speck of yellow in the middle, near the top.

'A mixture of 1 part of marsh-gas with 16 parts of air gave a voluminous, waving, spindle-shaped blue cap, $3\frac{3}{8}$ inches high.

'1 to 18—A similar cap, 2 inches high, which burned rather more steadily.

'1 to 20—A cap, $1\frac{5}{16}$ inch high, with nearly parallel sides to about two-thirds of its height, and drawn out to a point at the top. This cap was perfectly steady, and more distinct than any of the others.

'1 to 25—A conical cap, $\frac{1}{2}$ to $\frac{5}{8}$ inch high.

'1 to 30—A conical cap, $\frac{3}{8}$ inch high.

'1 to 40—A conical cap, $\frac{3}{16}$ to $\frac{1}{4}$ inch high.

'1 to 50—An exceedingly faint cap, $\frac{1}{8}$ inch high, the top having the appearance of having been broken off.

'1 to 60—It was hardly possible to distinguish anything above the small oil flame. If there was any cap, it was represented by the frustrum of a cone, of which the sides only were visible, little more than $\frac{1}{16}$ of an inch high.'

Mr. Galloway, in conclusion, states 'that a mixture of fire-damp and air, in the proportion of one part of the former with 60 parts or more of the latter, gives no reliable indication of the presence of inflammable gas, when tested in the manner usually, if not always, adopted in mines.'

A very ingenious instrument for detecting the presence of marsh-gas has been recently patented, in which the difference in the diffusive rate of marsh-gas over air has been taken advantage of. This instrument is more sensitive than a Davy lamp for indicating the presence of marsh-gas, but is rarely used. The instrument to which we refer is the 'fire-damp indicator,' invented by Mr. Ansell, of the Royal Mint.

Acetylene.

Symbol C_2H_2. Molecular weight 26.

This gas is never found native, but is produced at a high temperature by passing olefiant gas, vapour of ether, or alcohol, through a red-hot tube. It is also formed by the direct union of carbon and hydrogen at a high temperature, by passing a powerful current of electricity between carbon poles in an atmosphere of hydrogen. Acetylene is a constituent of coal gas, and can be prepared from it by imperfect combustion, and collected as a compound, by passing the gases through an ammoniacal solution of cuprous chloride, and then decomposing the red compound formed by hydrochloric acid, when acetylene is evolved. Acetylene does not support combustion, but burns in air or oxygen with a very bright and luminous flame. It is colourless, but possesses a peculiar odour, which is that evolved from a candle burning with a smoky flame. The serious explosions which have taken place during the cleaning of old copper gas-mains are believed to be due to a compound of this gas with copper oxide, which had adhered to the tube.

Acetylene forms explosive compounds with copper and silver.

Olefiant Gas

(Ethylene, or heavy Carburetted Hydrogen).

Symbol C_2H_4. Molecular weight 28.

Olefiant gas is formed by the direct union of acetylene and hydrogen. It is one of the chief illuminants of coal gas, and is produced during the destructive distillation of coal and carbonaceous matter, together with other gases absorbed by fuming sulphuric acid. Bischof found that this gas was present in the gases evolved by German coal from the Saarbrück coal-field. It is prepared for experiment by heating alcohol with six times its weight of strong sulphuric acid and this is the readiest mode of preparation. The gas generated is not pure, but may be considerably purified by passing it through two bottles, one containing strong sulphuric acid, and the other a thin mixture of slaked lime and water. It is one of the condensable gases, and is converted into a liquid at – 110° C. under great pressure. It is colourless and inodourless when pure, and burns with a very luminous flame, but it is incapable of supporting combustion. It is powerfully explosive when mixed with air or oxygen, much more so in fact than marsh-gas, requiring three times its volume of oxygen for complete combustion, and, volume for volume, it produces twice as much carbonic acid as marsh-gas.

When olefiant gas is passed through a red-hot tube, it is resolved into marsh-gas and carbon. An interesting experiment can be performed with this gas, which can be obtained sufficiently pure from alcohol by heating that fluid with sulphuric acid, as mentioned, and collecting the gas in tubes over water. To a tube or cylinder, two-thirds full of chlorine (made by treating 1 part common salt and 1 part of oxide of manganese with 2 parts of sulphuric acid, cautiously mixed with 2 parts of water, in a flask with a bent tube arrangement, and heated moderately), one-third of olefiant gas is added, and after standing for a short time a light is applied to the mouth of the cylinder—a yellowish flame passes slowly down, attended generally with a dull humming sound, and a large quantity of finely-divided carbon is deposited.

The specific gravity of olefiant gas is ·9784. It dissolves very sparingly in water or alcohol. It constitutes from 3 to 5 per cent. of coal-gas by volume, and is absorbed with other hydrocarbons of the same series, by fuming sulphuric acid.

Hydride of Ethyl.

Symbol C_2H_6. Molecular weight 30.

1 litre of the gas at 0° C. and bar. 760 mm. (30 in.) weighs 1·344 gram.

1000 cubic feet of the gas at 32° F. and bar. 30 in. weigh 83·758 lbs.

Hydride of ethyl belongs to the paraffin series, and is evolved from the earth in the neighbourhood of petroleum springs, and escapes, together with the oil, mixed with large quantities of marsh-gas, carbonic acid, and nitrogen. It was obtained by Dr. Meyer, of Germany, as one of the constituents of the occluded gases in coal, and also by the author in the gases enclosed in English and Scotch cannel coal, and recently in some of the steam coals of South Wales. It is present in notable quantity in the gases obtained from Wigan cannel.

The specific gravity of hydride of ethyl is 1·075, being nearly double that of marsh-gas. Owing to its superior density it does not escape so readily as marsh-gas, and it is very probable that the blower or self-evolved gases in the mines where Wigan cannel is worked would not contain more than 1 per cent. of this gas. It is very explosive, and consumes 3·5 times its volume of oxygen, and forms twice its volume of carbonic acid. It is soluble in alcohol to the extent of about 1½ volumes of gas in 1 volume of spirit, but practically insoluble in water. It is colourless and inodourless when pure, and is incapable of supporting combustion, but it is inflammable, and burns with a luminous flame. This gas was discovered by Dr. Frankland, who prepared the first artificial sample by acting on zinc-ethyl with water.

A gas, identical in composition, called methyl, was discovered by Kolbe, but it differs from ethyl hydride with regard to the compounds which it forms with chlorine.

Hydride of Propyl.

Symbol C_3H_8. Molecular weight 44.

This gas is the next highest in the paraffin series to hydride of ethyl, and, like it, has been found in the gases evolved from paraffin wells, and it has been detected by Dr. Meyer in gases obtained from some German coals. The Scotch cannels examined by the author also appear to contain this gas. It is soluble in alcohol, but almost insoluble in water. It is a colourless gas, possessing an ethereal odour, but when pure it is, possibly, inodourless.

Quartane.

Symbol C_4H_{10}. Molecular weight 58.

Quartane appears to be present in considerable quantity in jet (page 358), and it is not improbably a constituent of the gas enclosed in Scotch cannel. It is the next highest to propyl hydride in the paraffin series. It is a colourless gas, and very soluble in alcohol, from which it is given off readily on the addition of water. It is not probable that this or the preceding gas is evolved in any quantity in coal-mines—not more than traces arising from the getting of coal containing them. Coals containing this gas appear liable to become heated and partially decomposed under the influence of air and moisture when stacked in large bulk, but no instance of spontaneous combustion has come under the author's notice.

CHAPTER VIII.

SULPHUR—SULPHUROUS ACID, OR SULPHUR DIOXIDE—SULPHURIC ACID—SULPHURETTED HYDROGEN—CARBON DISULPHIDE—COAL GAS.

Sulphur.

Symbol S. Atomic weight 32.

SULPHUR exists in coal in the state of bisulphide of iron (FeS_2), and probably also as triferric tetrasulphide (Fe_3S_4). It is found in coal mostly in combination with iron as bisulphide FeS_2, commonly termed iron pyrites, or the 'brass' of the miner. Sulphide of iron is not unlike brass in appearance when it is distributed in laminæ between the fractures and slip cleavage of the coal. It occurs in crystalline nodules, either congregated together or disseminated throughout the mass of the coal. The yellow crystalline particles may be of appreciable size, or be so finely comminuted as to be invisible the naked eye, or even under the microscope. Some of the coals analysed by the author contained more sulphur than corresponded with the iron present in the ash, and, in one instance, much more than equivalent to the whole of the ash present, and there is no doubt that sulphur sometimes exists in coal in the state of organic combination. As an instance the following analysis may be given of a sample of bituminous coal (house coal) from a seam of unworked coal in one of Messrs. Insole & Son's collieries (South Wales coalfield).

Carbon	80·57
Hydrogen	4·38
Oxygen and nitrogen	6·17
Sulphur	4·24
Ash	4·15
Moisture	·49
	100·00

Of the 4·15 per cent. of ash, 3·60 per cent. consisted of oxide of iron, and there was no lime present; the remainder of the ash was composed almost entirely of silica and alumina. 1·08 of the oxide of iron is oxygen, and should rightly be added to the combined oxygen of the coal, leaving 2·52 per cent. of iron, which was present as sulphide in the coal. Now 2·52 per cent. of iron is equivalent to 2·88 per cent. of sulphur, taking it to have been present as bisulphide FeS_2, leaving 1·36 per cent. of sulphur unaccounted for, and the greater portion of which must have been free, or in organic combination. Dr. Percy, in his valuable work on 'Metallurgy,' mentions the fact of sulphur being found in coal in the state of organic combination, as it exists in hair for instance. It is not at all improbable, however, that it may be present in coal as free sulphur also. That sulphur may exist in coal in the free state is rendered more likely by the late researches of the author 'in the gases enclosed in lignite coal and mineral resin' (see Appendix, page 374). A crystalline sublimate of sulphur was obtained from one of the lignites (a very compact one too) at the temperature of 100° C. (212° F.), in a vacuum, and it is much more probable that the sulphur existed there in the free condition than in the state of organic combination, as the temperature and conditions were not favourable to the decomposition of a sulphur compound.

Sulphur is found in all coals (chiefly as sulphide), but in very variable proportion—some coals contain as little as ·5 per cent., and even less, while in others it is present in such quantity as to render them worthless as fuel; these latter are commonly known as brassy or stinking coal. The quantity of sulphur present in a coal is not dependant upon its character. Some anthracite coals contain less than ·5 per cent., and others as much as 3 per cent. Sulphur is present in some highly bituminous coals (especially in those near the outcrop of a coal basin) to the extent of 6 or 7 per cent., and steam coals in some instances contain 3 per cent. of sulphur.

Iron pyrites often occurs in masses in coal, and renders it worthless as fuel, but the pyrites is not unfrequently collected and disposed of for the purpose of making sulphuric acid. A really good and serviceable coal, whether steam, bituminous, or anthracite, should not contain more than 2 or 2·5 per cent. of sulphur, and much less would be preferable. When coals containing sulphur are burnt in a furnace, sulphurous acid is formed, and, if there is a good draught, a portion of the sulphurous acid is at once oxidised to sulphuric acid, which attacks the iron plates and copper tubes of engine boilers, and materially assists in their destruction. The presence of much sulphur in coal or coke is detrimental many metallurgical operations, and in the process gas manufacture during the destructive distillati of coal, some of the sulphur is converted in sulphuretted hydrogen and carbon disulphide. T former compound is easily removed during t ordinary process of purification to which the gas subjected, and recently it has been found possible remove the carbon disulphide to a very great exte leaving only some 8 or 10 grains per 100 cubic feet. is now practicable, therefore, to use coal having mo sulphur than could once be employed for gas-makin and this cannot fail to be a boon to the gas manufa turer, as many of the best coals adapted for g making contain a rather large percentage of sulphu

Thin white laminæ of sulphur, in combinati with lime and oxygen as sulphate of lime, are som times present in coal, especially near the outcrop a coal basin, where the waters are highly charg with sulphates. During the combustion of coal the sulphur is not evolved as sulphurous acid, b some frequently remains in combination with li and other bases in the ash, in rare instances to t extent of half or more of the sulphur present. however, the percentage of sulphur is high, and it in combination with iron as sulphide, no sulphur w remain, the iron being left in the state of oxid which may be either the sesquioxide, Fe_2O_3, or ma netic oxide, Fe_3O_4, according to the temperature which the coal was burnt, but it is usually present sesquioxide.

Coal containing iron pyrites yields an ash var ing in colour from pink-white to dark red or purp according to the quantity of pyrites present. The ash of sulphurous coals usually fuse, at a high temperature, and form, on cooling, the hard vitreous masses known as clinkers.

As we have previously noticed, all coals contain sulphur in some combined form, and this fact is recorded by Dr. Percy and other authorities; in the face of this it is remarkable that certificates of analysis of coal, purporting to have been carried out by a 'Government Analyst,' are to be found circulated in the coal trade, which state, in the most affirmative language possible, that a certain coal does not contain, or rather '*is absolutely free from the slightest trace of sulphur!*'

Sulphur is found native in Sicily and Southern Italy, near Naples, and many other parts of Europe. It is found also in Mexico and Tropical America. It has been produced largely by volcanic agencies, and is obtained in the clay formation in Sicily and in Iceland. In the native state it is met with either in opaque or crystalline masses of a yellow colour, or transparent crystals of an amber colour. Sulphur, in the combined condition, is, as we have noticed, present in coal, and the sulphide of iron is frequently met with in deposits, as also a sulphur compound containing iron and copper. Compounds of sulphur with zinc, lead, and other metals, are abundant in nature.

Native sulphur is purified by sublimation or distillation in earthen vessels or retorts, and condensed in similar retorts, which are perforated in the bottom and stand over water in which the sulphur is cooled as it runs through. Sulphur is obtained from the double sulphide of iron and copper—copper pyrites—by stacking an immense quantity of the roughly broken ore with alternating layers of brushwood, leaving an open communication in the centre, after the fashion of charcoal-burning. When several hundred tons have been thus piled, the whole is covered with ore-dust, and the mass lit in the centre. Underneath the pile a means of exit is afforded for the melted sulphur, which runs down and is drawn off and purified. In the manufacture of coal-gas, hydrated oxide of iron is employed as a purifying agent to remove sulphuretted hydrogen-gas. After the oxide has been partially sulphurised it is exposed to the air, when it is again resolved into oxide of iron, the sulphur remaining free. This process is repeated until the sulphur amounts to about 50 per cent. of the mixture, when it is distilled in retorts and the oxide of iron remaining becomes available for other purposes.

Sulphur is insoluble in water—tasteless and almost inodorous—of a lemon-yellow colour, and very brittle. Its specific gravity is 2·05. Sulphur melts at 114° C. (237° F.), and becomes fluid at a slightly higher temperature, but undergoes a remarkable transformation between 200° C. and 250° C. (392° F. to 482° F.), when it loses its limpidity and changes into a brown, viscid, treacle-like mass. If sulphur, melted at 446° F. (230° C.), be poured into water it solidifies, but loses its brittle character, and resembles caoutchouc, forming a soft, elastic, dark-coloured mass, which, however, in course of time, assumes its original yellow colour and brittle condition. The specific gravity of the elastic sulphur is 1·95.

Sulphur combines directly with the greater number of the elements, and supports the combustion of many of the metals. Finely-divided tin, lead, and silver, burn spontaneously in sulphur vapour, and zinc and iron at elevated temperatures. Sulphur is very inflammable—it takes fire in air or oxygen, at 250° C. (482° F.), and burns with a blue flame, forming sulphurous acid or dioxide, SO_2. The suffocating smell evolved when common matches are burnt is due to the formation of this gas. In the presence of moisture, more or less of the sulphur is at once converted into sulphuric acid, but in dry air, or dry oxygen, sulphuric acid is not formed. Sulphur is very soluble in carbon disulphide, excepting some of its modifications, as plastic sulphur, for instance, which is insoluble. Either free or in the combined state sulphur is gradually oxidised and dissolved when treated with strong nitric acid or aqua regia (a mixture of nitric and hydrochloric acids), with the formation of sulphuric acid, nitric oxide being evolved at the same time.

Compounds containing sulphur, when fused with nitre (nitrate of potash), or with nitre and carbonate of soda, yield sulphate of potash; the quantity of sulphur present can then be determined by estimating the amount of sulphuric acid and calculating the sulphur therefrom. Sulphur forms a variety of compounds and gases with hydrogen and oxygen, a few of which we will proceed to notice.

Sulphurous Acid

(Or Sulphur Dioxide).

Symbol SO_2. Molecular weight 64.

Sulphurous acid is always formed when sulphur is burnt in dry air or oxygen. It is evolved during the combustion of coke, and, to more or less extent, during the combustion of coal and other carbonaceous substances containing sulphur, and is also present in the gases given off from volcanoes. It is produced in the combustion of gunpowder, but is rarely found in coal mines except under these conditions. Sulphurous acid is an irrespirable, incombustible, and colourless gas, of a suffocating odour. It is readily condensed to a liquid under a pressure of fifteen atmospheres, or by the application of cold. When liquid sulphurous acid is subjected to extreme low temperatures it is frozen into a white solid. The specific gravity of the liquid oxide is 1·45, and the boiling-point $-10°$ C. For the purpose of experiment sulphurous acid gas may be obtained by acting on strong sulphuric acid with copper, in a flask furnished with a cork and bent tube arrangement, and the gas collected by displacement, *i.e.*, by placing the end of the bent tube near the bottom of the vessel in which the gas is to be collected. It is most conveniently collected over mercury, and water is not available for the purpose, owing to the gas being readily dissolved. The specific gravity of sulphurous acid gas is 2·247. It dissolves in water and f[illegible] an acid which is employed in the arts [illegible] res for a variety of useful purposes. It is used to preserve animal tissue and membranes, to bleach wool and straw, and for disinfecting habitations which have been visited by epidemic diseases. It is oxidised into sulphuric acid in contact with air or oxygen, and the salts of sulphurous acid, which are termed sulphites, are in like manner oxidised into sulphates.

Sulphurous acid is generated on a large scale in the manufacture of sulphuric acid. There is another oxide of sulphur—the trioxide, SO_3, obtained by distilling Nordhausen sulphuric acid—which forms dense white fumes in the air, and can be obtained as a crystalline solid at 10° C. (50° F.); by the addition of water it is converted into sulphuric acid.

Sulphuric Acid

(Oil of Vitriol).

Symbol H_2SO_4. Molecular weight 98.

This is the most important of all acids. It is produced as above, by adding the trioxide (sulphuric anhydride) to water—by the action of nitric acid on sulphur, and in a variety of other ways. It is estimated that about 150,000 tons of this acid are manufactured annually in this country. It is made, on the large scale, by burning sulphur or pyrites into sulphurous acid, and oxidising the sulphurous acid or sulphur dioxide into sulphuric acid by the aid of nitric trioxide and steam. The method of manufacture is as follows. Sulphur or pyrites is burnt in a furnace, and the sulphur dioxide evolved is conducted through a series of leaden chambers, where it meets with steam introduced through apertures in the sides. Nitric trioxide, obtained by the action of sulphuric acid on nitre (nitrate of potash or nitrate of soda), is admitted into the acid chamber, and acts as a carrier of oxygen to the sulphur dioxide, which becomes oxidised into sulphuric trioxide, and which latter, in the presence of moisture, forms sulphuric acid. In some manufactories the iron pyrites or sulphur is placed on an iron bed, which can be heated from below, and so arranged that a regulated current of air can be admitted over the sulphur in order to burn it at the rate required. On this iron bed the nitrate of soda pot is also placed for the generation of nitrous vapour. It is, however, preferable to admit the nitrogen oxides direct into the chamber, without coming in contact with the sulphur dioxide in the act of being generated. Sulphur dioxide is but slowly oxidised in the air, but in the presence of the higher oxides of nitrogen and steam, it is readily converted into sulphuric acid. This oxidation is chiefly accomplished by the trioxide of nitrogen, N_2O_3, which gives up an atom of oxygen to the sulphur dioxide and becomes reduced to nitrogen dioxide, N_2O_2, which immediately seizes another atom of oxygen from the air, only to be again reduced to nitrogen dioxide by more sulphur dioxide. Were it not for the tendency to waste the nitric trioxide by its passing off with the free nitrogen of the gases present in the chambers, a very small quantity of this gas would be sufficient to oxidise an unlimited quantity of sulphurous acid. The leaden chamber or chambers are in connection with a tall stack or tower in which [illegible] steam is circulated, and the condensed products are, for the most part, secured from passing off into the atmosphere.

The acid which condenses in the leaden chambers is allowed to remain until it reaches a specific gravity of from 1·5 to 1·6, when it is run off into shallow leaden pans and concentrated until it reaches a specific gravity of about 1·7. It is then transferred to glass or platinum retorts, and heated until a specific gravity of 1·84 is attained, which is about the density of the sulphuric acid of commerce. It is an extremely powerful acid, and is capable of displacing nearly every other acid at a boiling temperature. It is a heavy, oily liquid, without smell, and colourless when pure (commercial oil of vitriol is of a brown colour). Sulphuric acid acts very destructively upon organic substances, in many instances breaking up the compound entirely, and abstracting from it the elements of water. Sugar, wood, and allied substances are thoroughly carbonised. It is very hygroscopic, taking up water eagerly when exposed to the atmosphere, or from compounds which contain it. The addition of water to this acid produces much heat, so much, in fact, that it is necessary to add the acid to water very gradually, else the vessel in which they are mixed may be destroyed.

Sulphuric acid is found in combination with lime and other bases in the waters which traverse the coal measures, and also as sulphate of iron. Sulphuric acid is formed by the oxidation of iron pyrites in coal exposed to the atmosphere, especially in the presence of heat and moisture. Water which percolates through the upper coal measures containing iron pyrites conveys with it dissolved oxygen, which oxidises the sulphur of the pyrites with the formation of sulphuric acid, which displaces carbonic acid from the carbonate of lime held in solution in the water, and sulphate of lime results. Sulphates are also formed in coal mines, in old damp workings, by the oxidation of pyrites. Pyrites is believed by many to be productive of sulphuretted hydrogen, and that the action of moisture and air on it produces this gas. This theory is erroneous, as no sulphuretted hydrogen is formed under the circumstances, but only by the reduction of sulphates, which is a totally different reaction. Sulphate of iron, formed by the oxidation of pyrites, is identical in composition with the green copperas of the shops. Sulphuric acid combines with copper to form blue vitriol, or sulphate of copper, and the acid is used for cleaning iron plates before tinning or galvanising.

Sulphuric acid is very largely used in the manufacture of hydrochloric acid and carbonate of soda. Common salt (chloride of sodium) is treated in a kind of furnace retort with sulphuric acid, and, after the chlorine disposable without heat has been expelled, heat is applied to drive off the remainder, with the formation of sulphate of soda or salt cake. The hydrochloric acid is condensed in chambers, and the salt cake is reduced to sulphide by the action of carbon at a high temperature, and eventually converted into carbonate of soda.

Sulphuretted Hydrogen

(Hydrosulphuric Acid, or Sulphide of Hydrogen).

Symbol SH_2. Molecular weight 34.

1 litre of the gas at 0° C. and bar. 760 mm. (30 in.) weighs 1·523 grammes.

1 cubic foot of the gas at 32° F. and bar. 30 in. weighs 0·09492 of a lb.

When any strong acid is made to act on artificially prepared sulphide of iron, sulphuretted hydrogen gas is evolved, or when a current of hydrogen gas is passed through the vapour of sulphur the hydrogen unites with the sulphur and sulphuretted hydrogen results. It is prepared as a laboratory reagent, and for the purpose of experiment, by treating sulphide of iron with dilute sulphuric acid in a flask connected with another in which the gas can be washed.

The acid is best added, a little at a time, through a small funnel, the neck of which dips under the liquid in the flask in which the gas is generated. After preparing the gas the flask should be placed in the open air. It is very soluble in cold water, but less so in warm water, over which it may be collected. Water dissolves rather more than three times its volume of this gas at 15° C. (59° F.). The sulphuretted hydrogen water is slightly acid, and emits a very disagreeable odour, not unlike that of rotten eggs, which owe their abominable smell to the pres f sulphur gases. But sulphuretted hydro- n sulphide of iron is much more stinking than that made from sulphide of antimony, and the odour of the gas is, to a great extent, due to the presence of sulpho-carbon compounds produced by the simultaneous action of the acid on the sulphur and carbon contained in the iron.

Sulphuretted hydrogen is a condensable gas, and, under a pressure of 17 atmospheres, it becomes liquid and is capable of being frozen into an ice-like mass by the application of cold, or it may be liquefied and frozen by the aid of cold alone. It is not a supporter of combustion, but burns in air or oxygen with a blue flame, producing sulphur dioxide and water with more or less sulphuric acid. It is irrespirable, and when present in large proportions in air it exercises a poisonous action on the animal economy. It is not, however, so poisonous as is generally imagined, and when largely diluted with air may be inhaled for some time without serious results attending. Breathed in an undiluted condition it is fatal to life, and when diluted with ten times its volume of air it produces sickness, giddiness, weakness, and loss of sensation. Like carbonic oxide, it appears to act on the blood, and then on the brain, but it is not so fatal as carbonic oxide. It is absorbed into the blood and gives it a brown-black colour. Some authorities have stated that 1 part of the gas in 1,000 parts of air is fatal to animal life, and that half that quantity in the same number of parts of air is fatal to small birds. These conclusions appear to be erroneous. Duchâtelet states that workmen do not suffer in an atmosphere containing 1 per cent. of this gas, and that he inspired air containing as much as 3 per cent. for some time, without experiencing any ill effects.

It is not probable, however, that it can be breathed in such quantity with impunity. The only antidote for asphyxia from sulphuretted hydrogen is chlorine, which requires careful administration. The specific gravity of sulphuretted hydrogen (compared with air) is 1·178, and the composition—

	By Weight	By Atoms
Sulphur	94·12	1
Hydrogen	5·88	2
	100·00	2 atoms condensed.

When a mixture of sulphuretted hydrogen and oxygen is ignited it explodes, with the formation of sulphurous acid and water, with more or less sulphuric acid. The author found by experiment that when sulphurous acid is mixed with marsh-gas, and there is insufficient oxygen present for the complete combustion of the marsh-gas, the sulphurous acid gives up its oxygen, and combines with some of the hydrogen of the marsh-gas to form sulphuretted hydrogen. During an explosion in a coal mine, therefore, this gas would be generated in minute quantity by the breaking up of the sulphurous acid, or by the action of nascent hydrogen upon the sulphur of the pyrites in the coal dust. As before stated, sulphuretted hydrogen is formed when hydrogen is passed into sulphur vapour, and marsh-gas repeatedly heated with sulphur, or even passed into sulphur vapour at a high temperature, yields more or less sulphuretted hydrogen. Several cases of asphyxia, some of which proved fatal, have been attributed to the presence of this gas. In one instance, concerning the death of six individuals, the case was investigated by Dr. Taylor, and is given by him in his 'Manual of Medical Jurisprudence,' p. 438, from which we quote the following:—'In June, 1857, six persons lost their lives by the respiration of sulphuretted hydrogen in a diluted form, by reason of their having slept in small, close, ill-ventilated rooms into which the gas had penetrated. Three of the deceased persons had retired to rest in their usual health on the night of the 9th of June. Two of them were found the next morning dead, and a third (the child) in a state of insensibility, and died in the afternoon. The fourth, a healthy adult, retired to sleep in bed with his door closed, and died in an hour. The fifth, a child, was taken ill on the morning of the 11th, and died the same day, and the sixth was taken ill on the 10th and died on the 12th of June. The symptoms complained of by some who recovered were nausea, sickness, giddiness, and insensibility.' Dr. Taylor, on visiting Cleator to investigate the case, found that the cottages were built upon the slag from iron furnaces, and he states that the 'slag contained sulphide of iron and sulphide of lime, among other matters. A foul smell, similar to that evolved by cinders quenched with water, had been perceived about the rooms for some time, chiefly at night, when the doors were closed; and the day before the occurrence a heavy storm of rain had washed through the slag heap.' Dr. Taylor further states that the slag heap was still burning, and that sulphuretted hydrogen was evolved between the stone flags—the slag under which was found to be damp after their removal, and the presence of the gas detected; and that the occupants lost their lives hrough breathing it—a verdict being returned to that effect. It was suggested that the symptoms pointed to carbonic acid, and that this gas caused death; this was, however, proved to be impossible. Another theory put forward was that carbonic oxide in the vapours from some blast furnaces had found its way into the rooms where the persons had died; but the nature of the locality and the distance of the furnaces rendered this impossible.'

We have quoted from this case at some length, in order to show the necessity of guarding against the building of cottages on slag heaps or in positions where gaseous exhalations from the coal measures may gain access to them. We cannot, however, endorse Dr. Taylor's opinion with regard to the actual cause of death, although we do not doubt for a moment that sulphuretted hydrogen was present. It is probable that death was attributable to the inhalation of several gases—sulphuretted hydrogen, carbonic oxide, carbonic acid, &c. There was no necessity to look so far as the *vapours* issuing from blast furnaces for the presence of carbonic oxide—the slag-heap was burning, and the mere fact of water coming in contact with the fire would give rise to the breaking up of the former into its constituent gases, oxygen and hydrogen—the oxygen would go to oxidise carbon into carbonic oxide and carbonic acid, nd the hydrogen to form sulphuretted hydrogen and robably hydrocarbon gases; and the smell observed, ke to that 'of quenching hot cinders with water,' was doubtless due to the formation of these gases, by he action of water on the incandescent matter: so hat death can be mainly attributed to the inhalation of carbonic oxide, accelerated doubtless by sulphuretted hydrogen and carbonic acid. Sulphuretted hydrogen emits an abominable odour, especially when generated under the circumstances noted, and its presence must have been detected before it could accumulate in sufficient quantity to cause death in so short a time.

Several accidents in coal mines have been reported as due to the effects of sulphuretted hydrogen, and, in fatal instances, it has been stated that lights burnt well in the atmosphere which produced these results. The foregoing remarks in reference to the smell of this gas apply also to these latter cases, and they can, most probably, be far more safely attributed to the presence of carbonic oxide in the atmosphere of the coal mine, as carbonic oxide can be present in amply sufficient quantity to prove fatal, without affecting the flame of a lamp or candle.

Sulphuretted hydrogen is generated in small quantity in coal mines, more especially in old worked portions which are partly filled with water. By the action of oxygen dissolved in water, sulphates are formed, as already stated, and the water which gains access to old workings is not unfrequently highly charged with them. The timber used for props and supports undergoes decomposition in water, and, in so doing, breaks up the sulphate of lime and assimilates its oxygen, the nascent sulphur seizing probably the hydrogen of the wood to form sulphuretted hydrogen. It is not formed by the decomposition (*oxidation*) of pyrites, as stated in some works treating on coal mining. It is generated in sewers and from organic compounds containing sulphur in the act of undergoing decomposition.

This gas is invaluable to the chemist, as by its aid the metals are separated from one another. There is another compound of hydrogen and sulphur known as bisulphide of hydrogen. It is obtained by acting on bisulphide of lime with hydrochloric acid. It is an oily liquid, having a peculiar odour, and possesses the property of bleaching vegetable colours. It is decomposed very readily into sulphuretted hydrogen and sulphur, and it consists of two atoms of hydrogen and two atoms of sulphur, H_2S_2.

Bisulphide of Carbon.

Symbol CS_2. Molecular weight 76.

This volatile liquid is formed during the destructive distillation of coal and organic substances containing sulphur. The vapour of sulphur passed over red-hot charcoal gives rise to this compound, but sulphur and carbon heated together do not yield it, as the sulphur volatilises before the necessary temperature is reached. It is a colourless liquid of very high refractive power, and emits a peculiar odour. Its specific gravity at 15° C. (59° F.) is 1·27. It boils at 46·6° C. (116° F.).

Bisulphide of carbon is highly inflammable, igniting at a low temperature, and evaporates very quickly at the ordinary temperature of the atmosphere. It is not soluble in water, but ether and alcohol mix with it readily, and it forms an excellent solvent for many substances which are for the most part insoluble in the majority of other reagents, such as phosphorus, iodine, sulphur, oils, fats, camphor, gums and caoutchouc. It is very volatile, and the vapour is poisonous. The bisulphide of carbon present in coal-gas is converted during the combustion of the latter into carbonic acid and sulphuric acid.

Coal Gas.

A very important use to which coal is applied is the production of gas for illuminating purposes. So general has the use of coal-gas become, that even small villages are lit at night with it.

All kinds of coal yield gas when submitted to destructive distillation in retorts, but all coal is not available for making gas for illuminating purposes, owing to their not containing sufficient hydrogen to yield hydrocarbons of such a density as shall confer upon the gas the property of giving a good light. True anthracite and anthracitic steam-coals do not contain as a rule more than 3·5 per cent. of hydrogen, but bituminous coals suitable for gas-making contain a much larger quantity. Of all the coals used for gas-making, cannel is the best adapted; but the coke is not usually so valuable as that made from a good bituminous coal which does not contain much ash. The following analyses show the composition of Wigan cannel by Vaux and Lêsmahago cannel by Miller.

	Wigan Cannel	Lêsmahago Cannel
Carbon	80·07	73·44
Hydrogen	5·53	7·62
Nitrogen	2·12	11·77
Oxygen	8·08	
Sulphur	1·50	1·14
Ash	2·70	6·03
	100·00	100·00

Coal-gas is manufactured in closed retorts of cast-iron or fire-clay. According to the quantity required, a number of these retorts are placed side by side, all of them communicating with what is termed the hydraulic main. Here the greater portion of the tarry matter and some of the more liquid products are condensed. The gas next passes through a number of pipes, which afford a large cooling surface, where the ammoniacal liquors are further deposited, and from thence through an upright cylindrical apparatus in which the gas is exposed to the action of steam or water, and undergoes what is termed the scrubbing process. It is further deprived of sulphuretted hydrogen and carbonic acid by being passed through layers of oxide of iron and slaked lime, after which the gas is forced by steam power into the meters, and distributed for consumption. Of late years the manufacture of gas has received marked attention, and the apparatus used for purifying it has been very considerably modified and improved, but the limits of this treatise will not allow entering into detail upon these important additions.

The quality of gas made from coal differs to a very great extent. Many of the coals employed do not yield gas of sufficiently high illuminating power, and it may be, in the majority of instances, that more or less cannel is used in order to add to the illuminating power of the gas produced. The following analyses of coal-gas by the author will show the difference between gas made exclusively from cannel (No. 1), and that made from ordinary coal (No. 2). Nos. 1 and 2 were supplied to the South Kensington

Museum, London. No. 3 is an analysis of the gas supplied by the Cardiff Gas Company :—

	Composition per cent. by Volume		
	No. 1	No. 2	No. 3
Carbonic acid	2·49	0·18	0·13
Oxygen	·33	·17	·31
Olefiant gas and gases of the olefiant series	8·95	4·16	4·41
Hydrogen	39·69	49·98	47·32
Marsh-gas	36·27	36·35	38·21
Carbonic oxide	9·33	6·24	7·79
Nitrogen	2·94	2·92	1·83
	100·00	100·00	100·00

The illuminating constituents of coal-gas are olefiant gas and other gases belonging to the same series, which are removed from coal-gas by fuming sulphuric acid. Olefiant gas is composed of 2 atoms of carbon united with 4 atoms of hydrogen, C_2H_4—other gases of the same series would be those which, when deprived of 1 atom of carbon and 2 atoms of hydrogen, CH_2, or any number of carbon and hydrogen atoms in the proportion of one of the former to two of the latter, would leave, as a remnant, CH_2 or C_2H_4; thus C_3H_6, C_4H_8, would be gases of the olefiant series.

It will be seen at a glance that No. 1 gas is much richer in illuminating power than either No. 2 or 3. Carbonic acid, oxygen, and nitrogen are regarded as impurities in coal-gas, while hydrogen, carbonic oxide, and marsh-gas, although they do not add to the illuminating power of the gas, afford he material, and are termed diluents. Coal-gas other impurities of a more objectionable character than carbonic acid, &c., as bisulphide of carbon and ammonia.

Carbon disulphide yields, on combustion, sulphuric acid as one of its products, which destroys and blackens silver and gilt goods, and oil-paintings which contain lead and other metallic pigments. Sulphuretted hydrogen is so easily removed from gas that it is seldom present in that supplied for consumption.

Coal-gas, like marsh-gas, is very explosive when mixed with air, and many serious explosions have happened in consequence of the gas finding its way by leakage into rooms, and becoming ignited.

Coal suitable for gas-making should yield at least 9,000 cubic feet of gas of an illuminating power equal to 15 candles. Many of the cannel coals yield from 10,000 to 13,000 cubic feet of gas, of an illuminating power varying from 17 to 30 candles. A somewhat sulphurous cannel from a mine near Pontypool, recently examined by the author, gave 12,226 cubic feet of gas per ton of coal, of an illuminating power equal to 26·8 candles, while an ordinary bituminous coal from the same mine yielded 10,542 cubic feet of gas per ton of coal, of an illuminating power equal to 17·95 candles. Of the South Wales coals, the Energlyn, Llwynypia, and Llantwit are good for gas manufacture; there are also many others suitable for the purpose. Some of the Newcastle and Durham coals are excellent for gas making.

Unfortunately there is no easy and accurate method of estimating the illuminating value of coal-gas. A graduated tube, bent in the shape of a U, was formerly employed, into which a little chlorine or bromine was introduced and brought in contact with the gas, and from the loss in volumé caused by the absorption of the gases of the olefiant series by the bromine or chlorine, the illuminating power was calculated. The illuminating value of coal-gas is now generally determined by the aid of an instrument known as a photometer, which consists of a graduated bar, on which slides a movable disc having two reflectors. The disc is made of stout paper, one portion of which is rendered semi-transparent, and the other left opaque, for the purpose of affording a means of adjusting the disc at a point where the shadows from the two lights will be equal. On one end of the bar is fixed the gas-burner consuming gas at the rate of 5 cubic feet per hour, and at the other end two sperm candles are held suspended from a balance. When the disc is adjusted so that the shadows are equal, the graduations on the bar show the equivalent of the gas in candles, which, however, requires correction for temperature, pressure, and irregular burning of the candles, which although calculated to, seldom burn at the rate of 120 grains per hour.

The most accurate method of arriving at the illuminating value of coal-gas is by subjecting it to a complete analysis in a gas apparatus, which is, however an expensive instrument, and requires considerable skill in its manipulation.

Recently other photometers have been invented, whose respective merits have scarcely been determined. They are worthy of mention for their novelty and scientific principles. One is based upon the character of selenium when exposed to light and darkness. Another is the 'radiometer,' the discovery of Professor Crookes, F.R.S. Neither of these has been used. A simple and ingenious instrument sold by Sugg of Westminster indicates the illuminating power of gas by the height of the flame at a given pressure.

After the coal has been subjected to distillation in the retorts, the coke which remains is taken out and quenched with water. The coke amounts to from 40 to 70 per cent. of the original coal, by weight. The ash present is naturally in excess of that originally in the coal—the volatile or combustible portion only escaping, and if 70 per cent. of the coal remains in the form of coke, it will contain $\frac{10}{7}$ as much ash as the coal did. In other words, if a gas coal, before being placed in the retort, contained 3 per cent. of ash, and it yields 50 per cent. of coke, then the coke will contain 6 per cent. of ash or thereabouts.

The compounds which are condensed during the manufacture of coal-gas are very varied and valuable, and the money value of the products obtained yearly from coal-tar itself must be astonishingly great. The beautiful colours or woollen dyes, known as 'anilines' are coal-tar products. The gas liquor is a fertile source of ammonia; naphtha, creosote, carbolic acid, and other important compounds are obtained from gas refuse.

CHAPTER IX.

EXPLOSIONS IN COAL MINES—EXPLOSIONS ON BOARD-SHIP.

It would be well if a chapter thus headed were out of place in any treatise, but unfortunately explosions in coal mines are of frequent occurrence, and it becomes necessary to take into consideration the cause, origin, and effect of these calamities.

In the formation of coal, the organic matter from which it is derived has undergone a process of change, liberating, at the same time, various gases which according to the reaction which has taken place, and the nature and depth of the coal and superincumbent strata, may be explosive or non-explosive. We have already described the nature of the gases enclosed in coals, and the papers in the Appendix show the percentage, composition, and quantity of the gases present.

In the working of a great many varieties of coal, there is no danger of an explosion taking place, owing to the entire absence of explosive gas, and, generally speaking, explosions happen only in mines where steam coal is worked, or where semi-bituminous and bituminous coals are won at considerable depths below the [illegible] In these instances during the conversion of the organic matter into coal, the hydrogen has in great part been eliminated as marsh-gas, which, owing to great pressure and the impermeable character of the strata above, became imprisoned and condensed in the pores or interstices of the coal and shale, and in all available cracks, fissures, and receptacles in the strata. In those seams or veins situated in what has been called the marsh-gas or fiery zone of a coal-field, at some depth from the surface, and which are consequently under vast pressure, immense volumes of gas are stored up. As soon as a communication is afforded by working a seam of coal, a means of exit is furnished to the imprisoned gas, which finds its way continually into the workings by percolation through the coal, through the crevices and fissures in the rock, and through the intermediate shale; and by diffusion with the air forms an explosive mixture. This mixture is capable of exercising a mighty force, and on ignition it robs the air of its oxygen, and generates, as the result of imperfect combustion, gases of a poisonous nature. Devastation and death follow the ignition of this mixture and of fire-damp and air, and the mortality in the mining districts is augmented in no slight measure through the occurrence of explosions.

We will notice, first, the result of atmospheric influences, and those of other terrestrial phenomena upon the liberation of gas in increased quantity; secondly, the means by which an explosive mixture may become fired; and, thirdly the results, and resulting products of the combustion of explosive mixtures.

It is impossible that any state of the atmosphere either under the influence of temperature, dry winds, frosty weather, or low barometric pressure would be sufficient, at any season of the year, to account for the almost simultaneous occurrence of several explosions, but there is no doubt that they greatly augment the evils which result.

The atmosphere under ordinary conditions of temperature and pressure is invariably humid, and in those parts of a mine which are removed from the direct air-currents, almost always saturated with aqueous vapour, generally at a temperature considerably above that which exists at the surface. During the prevalence of frost, accompanied by dry wind, the aqueous vapour in the atmosphere is reduced to the minimum, and in its passage through the mine the air becomes elevated in temperature. Every trace of moisture is eagerly taken up, and the working face of coal, galleries, rocks, and all exposed material, are found to be in an extremely dry condition. Under these circumstances there is doubtless some shrinking, and there is a tendency to offer increased facilities for the escape of gas. It is hard to determine the extent to which the 'top' may suffer, or the rock is prone to crack, and accelerate a fall in consequence, but it is obvious that, charged and surrounded as a seam of coal is by gas under vast pressure, very little would tend to add to the quantity evolved.

The coal-dust, incidental upon working, which coats more or less the entire galleries or headings, as well as forms a bed of some thickness on the floor, is also rendered very dry. Mr. Galloway, Assisting Inspector of Mines, in his report on the Llan explosion appeared to attach much importance to the pr of coal-dust as being the means of causing an explosion when the percentage of marsh-gas was very low. He observes, that 'he discovered, some three or four months previous, that a mixture of air and fire-damp, which could not be ignited by a naked light, immediately became inflammable when coal-dust was mixed with it.' More than twelve months prior to this, the author made some experiments with Nixon's 4-ft. vein, from the Navigation Colliery, in order to determine to what extent coal-dust would influence the ignition of mixtures of marsh-gas with more than 14 parts of air, but was unable to obtain any definite results; and while engaged with these experiments, it transpired that in Germany, the miners who work bituminous (deep) coals in the Zwickau and Saarbruck basins, had long known that coal-dust tended to cause the mine-gases to ignite when present in otherwise non-explosive quantity. The particles of coal-dust partially consumed in the flame of a lamp or candle evolve hydrocarbons of a more complex character than marsh-gas, and consequently render the surrounding air in a mine more explosive, and the miners are very careful to keep their lights as far as possible from the working face. On the Continent, in fact, in many collieries covered lights are used, owing almost entirely to the reason stated.

The author's experiments would not have given much satisfaction if persisted in, owing to the apparatus used being too small in diameter. It is probable, however, that anthracite coal-dust does not add much to the explosive nature of a mixture, but when an explosion occurs it is partially consumed and the heat generated assists combustion in a degree dependent upon the minuteness of division of the coal-dust.

In the *Annales des Mines* for 1875, M. Vital, a French mining engineer, describes the result of an explosion which took place in the Campagnac Colliery in 1874, in the apparent absence of fire-damp, and said to be caused by the effect of a shot raising a cloud of coal-dust, which, it is alleged, became ignited and gave rise to the explosion. M. Vital carried out some experiments with fine coal-dust and air, and found that in the entire absence of fire-damp such a mixture was explosive, or at least it was capable of undergoing combustion.

We have already referred to Mr. Galloway's paper in the 'Journal of the Royal Society, 1876,' in reference to his experiments on the Davy lamp, as an indicator of the presence of marsh-gas; the same paper also includes the result of experiments 'on the influence of coal-dust in colliery explosions.' Mr. Galloway quotes the following passage from M. Vital's paper, which is, in fact, the substance of the conclusion deduced by the author, 'Very fine coal-dust is a cause of danger in dry-working places in which shots are fired: in well-ventilated workings it may of itself alone give rise to disasters; *in workings in which fire-damp exists it increases the chance of explosion*; and when an accident of this kind does occur, it aggravates the consequences.'

Mr. Galloway observes that he had come to a conclusion somewhat different from this, which was 'that air mixed with certain proportions of fire-damp and dry coal-dust would be explosive at ordinary pressure and temperature, although the presence of the same proportion of one of the combustible ingredients, or the other alone, might be insufficient to confer this property on the mixture.' (Does not M. Vital's sentence given above in italics embrace Mr. Galloway's conclusions?)

Mr. Galloway, in summing up the results of his experiments, states that they show conclusively that *a mixture of air and coal-dust is not inflammable at the ordinary temperature and pressure.* Some of the bituminous coal-dust was dried and sifted before being used. The following are the analyses of the two samples of coal-dust which he employed :—

	Steam Coal-dust.	Bituminous Coal-dust.
Carbon	85·295	82·57
Hydrogen	5·040	5·40
Oxygen (by difference)	1·261	6·03
Nitrogen	·608	1·05
Sulphur	·692	·80
Moisture	·614	·67
Ash	6·490	3·48
	100·00	100·00

The fire-damp used by Mr. Galloway was taken from the 'blower' at Llwynypia colliery, and the analysis of the gas was done by the author. After finding that a mixture of air and coal-dust was not explosive, Mr. Galloway tried some experiments in order to determine how much fire-damp must be present before coal-dust would form an explosive mixture with air, and found that when ·892 per cent. was added, the mixture was rendered explosive.

If the figures of the above analyses are taken into consideration, it will become evident, especially on comparing the hydrogen, that what is styled 'steam coal' may with equal truthfulness be called 'bituminous.' The name of the coal is not given, but let us presume that which appears most probable, that both are from the Llwynypia colliery. Now the 'steam coal' is an excellent free burning coal, and one which contains heavy hydrocarbon gases. Some of the heavier gases are retained in the small of this coal for a considerable time, and, in point of fact, it is a coal the dust of which would be as likely to ignite as that from some of the bituminous coals, and would give off gas when it came in contact with a heated atmosphere or flame at a high temperature. With regard to the bituminous coal-dust, the analysis represents that of a superior caking coal, but it is certainly, so far as the bituminous quality is concerned, little above the average of the coals of its class. There are many coals in the South Wales basin much more bituminous than this, especially those worked near the outcrop.

It will be seen that the 'steam coal' dust bears little or no relation to that of the Aberdare steam coals ('*dry coal*'), such as the 4-ft. vein, for instance, and if the former would not form a combustible mixture with air, much more certain is it that the latter would not; while true anthracite coal-dust would exercise still less effect. So far, therefore, as the coals of the anthracite class are concerned, Mr. Galloway's conclusions regarding the non-combustibility of air and coal-dust are doubtless correct. It does not follow, however, that this is so with the bituminous coals, simply because the sample of bituminous coal-dust employed did not form a combustible mixture with air; on the contrary, Mr. Galloway's subsequent experiments upon the quantity of fire-damp required to be present, in order to form an explosive mixture with coal-dust and air, prove, we think, the possibility of bituminous coal-dust forming *of itself* a combustible mixture with air. We will endeavour to illustrate this more plainly. Taking the explosive limit of a mixture of the fire-damp used, and air at 1 in 15, which implies 6·6 per cent. of fire-damp, it is evident from Mr. Galloway's experiments, that the presence of coal-dust is equal to 5·774 per cent. of fire-damp, or more than 86 per cent. of the total required. If then, a coal-dust of superior bituminous quality were employed, it is very probable that it would be inflammable when diffused in air, without any fire-damp being present; and, apart from any desire to disparage Mr. Galloway's experiments in the slightest degree, we do not think they are sufficiently conclusive to support the deductions which he draws from them, because his experiments should not have been confined to coal-dust from a single colliery. Moreover, there is considerable difference in the combustibility of different samples of coal-dust which agree very nearly in chemical composition.

Then again the dust of cannel coal such as that from the *fat* coals of the Lancashire coal field, would, we think, be capable of forming an explosive mixture with air, if it only require ·892 per cent. of marsh-gas to render the Llwynypia coal-dust inflammable, and we are not inclined to doubt the experiments of M. Vital without further proof. It is not probable that the drying of the coal-dust, as recorded by Mr. Galloway, would add to its inflammable properties; on the contrary, some of the more volatile and certainly inflammable portions of the coal would be driven off.

As a rule those coals which form most dust at the working face lose, somewhat readily, a great portion of their volatile oily matters, and become less liable to aid in starting an explosion. In many of the bituminous coal mines, some of the slight explosions which have happened originated in consequence of the effect of coal-dust, while in others coal-dust has doubtless extended the field of the explosion.

The terrible results of the great explosions which have occurred are due chiefly to fire-damp (marsh-gas), and it is the effects of this gas which more especially claim the miner's attention. In England and Wales the seams or veins which are most fiery are, for the most part, of the kind known as steam coal. These coals belong to the anthracite class, and contain only a small percentage of hydrogen, and it is possible that the presence of dust from these coals does not render a non-explosive atmosphere explosive, unless the coal is bituminous, or the fire-damp approaches 1 part in 16 parts of air. When an explosive mixture has become fired, the coal-dust doubtless takes an active part in consuming oxygen, and adds to the spread of the explosion.

The effects of decreased atmospheric pressure upon the quantity of gas evolved cannot be overrated. It may be assumed that the removal of a pressure equal to the weight of a column of mercury one half-inch in height could not seriously affect the imprisonment of the mine gas, as it would not reduce the pressure by one quarter of a lb. on the square inch. Such a reduction in pressure, however, when spread over a surface like that exposed in a mine is considerable, especially when the coal contains immense volumes of gas. Masses of rock crushed by the overwhelming pressure overhead, and, maybe, but imperfectly supported, would have a tendency to fall, and so open up a channel whereby an inundation of gas may find its way into the workings of a mine, or the cracking of the rock may also afford a communication with a fissure, carrying the feed of a 'blower,' which otherwise makes its exit on the surface, and the mine would, in consequence, be placed in a state of extreme danger. The diminution of barometric pressure is often very sudden, and the fall of half an inch mercury would doubtless be the means of causing a materially increased inpour of fire-damp. The connection between barometric and thermometric conditions of the atmosphere and explosions in coal mines has long been the subject of much speculation, and numerous papers have been written by mining engineers and others on the subject. A very elaborate plate, showing the explosions which have occurred through thermal and barometric influence, is given in a paper by Messrs. Scott and Galloway ('Journal of the Royal Society,' Vol. XX., 1872), 'On the Connection between Explosions in Collieries and Weather.'

Apart from the effect which decreased pressure exerts upon the release of fire-damp, other serious results follow in consequence. We shall notice these and the effect of temperature in detail under 'Ventilation.'

Several frightful explosions, which occurred almost simultaneously (1875), happened in the winter months, and in some cases during frosty weather. Now the effect of decreased barometric pressure, say equal to a fall of half or even of one inch, would, under such conditions, exert but little influence upon the ventilating current, since the low temperature of the atmosphere would more than compensate for the reduced pressure. It is much more easy to ventilate a colliery by introducing air at or near the freezing temperature under a low barometer, than by admitting the atmosphere at 70° F. under the influence of a high barometer.

The most feasible explanation, probably, which has ever been brought forward to account for the simultaneous occurrence of several explosions, and one which may exert considerable influence upon coal mines situated in portions of a coal-field which may have been previously disturbed by volcanic or other disarranging agency, is that of *contraction of the external shell of the earth.* Many are of opinion that the interior of our planet is in a state of incandescence and continually shrinking, and, as a natural consequence, the exterior or surface crust must subside. That this subsidence of the external shell of the earth is not always gradual and regular is said to have been proved by the observations which have been recorded on terrestrial magnetism in the various observatories. It has been noticed on many occasions that the suspended magnets have indicated disturbances at irregular intervals, both in inclination and declination, which cannot be attributed to the force of magnetism. Dr. Lloyd has attributed these movements to the dislocation of the earth's crust occurring not far from the surface.

The slightest rent in the rock above or below a seam of coal extending over a considerable area would be the means of liberating a vastly increased quantity of gas, while the terrestrial movements through which the rent was caused would not be sufficiently sensible to be felt. A colliery may be situated in a neighbourhood which has been disturbed previously, and intersected by faults which often extend through considerable distances, and would appear susceptible of undergoing a further change more readily than the undisturbed strata.

Earthquakes, which are the greater internal movements in our earth's crust, take place more frequently during the winter months, and, possibly, the lesser and more insensible movements to which we have referred may in like manner occur chiefly in the same season, and thus account for the prevalence of numerous explosions during the colder portion of the year.

With regard to the manner in which an explosive mixture may be ignited, much will depend upon the condition of the mine and the use of protected or unprotected lights. The flame of a candle or lamp will readily ignite a mixture of fire-damp and air, but it requires a very high temperature, which must be proportionately greater according to the concentration of marsh-gas. Clean charcoal and coke fires have been used for lighting in some old and rare instances, and although dangerous on account of the possibility of a flame arising, they will not ignite a mixture of fire-damp and air, provided they do not flame. A portion of a candle or lamp flame is at a fairly white-hot temperature, and nothing short of an intense heat will ignite fire-damp. We have noticed that a mixture of fire-damp with more than 15 parts of air will not ignite at ordinary pressure. This is partly due to the smallness of the body of fire used as the igniting agent, and partly owing to the cooling effects of so large a body of nitrogen. When the mixture consists of about 10 parts air and 1 part marsh-gas, the heat required to ignite it appears to be at the minimum, and increases according as the quantity of marsh-gas or fire-damp increases, and when it reaches 1 part in 5 parts of air the mixture cannot be ignited without the application of intense heat; in fact the temperature of the igniting body must be a great many degrees above that which will set fire to a mixture of fire-damp with 10 parts of air.

The illuminating agents used in coal-mines are candles and lamps, open or protected; the flame of all of these will set fire to explosive mixtures. In coal-mines worked in the fiery zone of the formation, safety lamps are almost invariably used, while in mines where there is little marsh-gas open lamps or candles are employed. Many explosions have happened in consequence of an explosive mixture taking fire at a naked light, while others of great magnitude—such as that at Ferndale, Rhondda Vach Valley, in 1867, with the loss of 178 lives—have occurred in consequence of the opening of the Davy lamp in order to get more light. Many explosions, some of them doubtless resulting in the loss of a considerable number of lives, have occurred through sheer negligence on the part of the men, or in other instances through ig[illegible]e danger.

Another way in which an explosive mixture can be ignited is through the firing of a shot, and the subsequent action of the sound-wave and propulsive force in driving the flame of the Davy through the wire gauze, and igniting the explosive mixture on the outside. Mr. Galloway made some experiments in this direction in order to try the effect of firing shots in collieries, and he found that it was possible to ignite an explosive mixture on the outside of the Davy lamp under varying conditions, by the firing of a pistol loaded with gunpowder. These effects are attributed to the sound-wave or particle to particle vibration of the air; but the question arises, How much of the potential energy is exercised by the direct force of the gases generated as the result of the combustion of the gunpowder, and to what extent does the so-called sound-wave take a part in the action?

With regard to the simultaneous occurrence of two explosions in different portions of the same mine, the force of the first in compressing the air would, like a hurricane, make itself felt for a long distance, and be the means of driving the particles of air—surrounding the Davy lamp—through it at such a velocity as to cause the flame to penetrate the wire gauze. Then again, the mere fact of the application of force implies compression and increased density of the air-current, while the flame under the circumstances noted would increase in intensity—results, therefore, which would offer extra facilities for starting an explosion in what would be probably an otherwise non-explosive atmosphere. Davy himself distinctly disclaimed having invented a lamp which would stand air-currents of varying velocities, and the late Dr. Pereira showed that if the Davy lamp was suddenly jerked in the hand, the flame was apt to pass through the gauze, and so ignite an explosive mixture. Under these circumstances, therefore, it is easy to understand that the concussion produced by an explosion in one part of a mine may have the effect of causing an explosion in another part of a mine in which there was an explosive atmosphere, or one near the point of becoming explosive, and explosive mixtures pent up in goaves, &c., would probably be dislodged by the sudden action of the explosive force. The Davy lamp is more sensitive to air-currents than any other, and this was confirmed by Mr. Galloway in his experiments on shot-firing; while those lamps which are most extensively used now—such as the modification of the Geordie, Eloin, Mueseler's, &c.—are not liable to pass flame outwards under the conditions mentioned.

When an explosive mixture has been ignited it expands to an enormous extent, on account of the intense heat generated during the combustion of the marsh-gas, and compresses the gaseous mixture immediately before it to a greater and greater extent as combustion proceeds. The frightful pressure exerted during an explosion in which a large quantity of marsh-gas has taken part is shown by the stupendous destruction which has resulted—the crushing to fragments of doors, the dislodgment of props and timbering, the shattering of air-crossings, the tearing up of rails and twisting and bending of the same, the smashing of trams and the partial burying of them in the solid coal, and the scattering of rock and rubbish in every direction.

On account of the great pressure, mixtures of marsh-gas and air which are inexplosive at ordinary atmospheric pressure, take a part in the explosion, and combustion extends through limits which have hitherto been regarded as impossible, and it is the effect of this pressure or explosive force which has tended so much to widen the 'field' of explosions in which it was known there was little gas and air in the proportions which ignite under ordinary conditions. The coal-dust present in the air-currents takes a part in the reaction, consuming a portion of the oxygen, and, in doing this, adds naturally to the extent of the explosion by maintaining the temperature and generating gas to keep the combustion of the mixture alive, and as this living flame is forced by pressure into fresh air containing gas in smaller and smaller quantity, combustion becomes more feeble, until ultimately the temperature falls too low and the explosion terminates.

Let us suppose that any portion of a considerable volume of an explosive mixture has been ignited or fired. The chemical combination of oxygen with the combustible gas (chiefly marsh-gas) gives rise to intense heat, which we will designate *primary heat.* Now the primary heat is converted into force or motion by reason of the great expansion of the ignited mixture, and this primary force exerts its energy in compressing the gaseous mixture immediately before it, and the result is that the primary force is partly transformed into what we will term *secondary heat.* Let the broken line A C D E ___B represent a gallery in which an explosion is taking place. The portion C of the gallery is occupied by an ignited mixture of fire-damp and air, which expands enormously, and compresses D with great force. The sides, top, and bottom of D offer considerable resistance to the compressed mixture as it moves onward with increased velocity, and before the flame of the explosion reaches E the temperature of the mixture will have been much raised, not directly by the *primary heat*, but by the primary force being partly expended in the production of *secondary heat.* At E, therefore, the flame of the explosion encounters an atmosphere of greatly *increased density at an elevated temperature.* Under these conditions it may be asked, what are the limits of an explosive mixture of air and fire-damp? Would bituminous coal-dust, raised in a cloud by the force of the explosion, be insufficient to form an explosive or inflammable mixture with air? or, in other words, would not the increased density and heat generated be equivalent to the presence of ·892 per cent. of fire-damp? These are questions which require careful consideration, and in the face of the circumstances enumerated it will be seen that experiments carried out under ordinary atmospheric pressures and temperatures are of little value in determining the limits of combustion in a mixture which has become ignited.

In some of the frightful explosions which have occurred recently, the flame of the explosion actually shot up above the mouth of the pit, while the stupendous force hurled everything before it, not excepting the framing of the winding-gear on the surface. What must have been the compression of the atmosphere in the galleries when driven before such a power? and [illegible] would be the quantity of heat (secondary heat) generated as the result of motion, &c.? Without doubt they must be enormous; and it is not at all improbable that the heat incidental to motion and compression rose so high as to cause the coal-dust, with which the mixture was charged in its progress, to undergo partial decomposition. In consequence of this, a mixture of air and coal-dust would be rendered eminently explosive through the gases generated by the heated coal-dust, and apart from any consideration respecting *secondary heat*, we are strongly of opinion that great compression alone would determine the inflammability of a mixture of bituminous coal-dust and air. The fact that in order to obtain motion (which implies heat) force is required, must not be lost sight of, however, and it is only in those instances where large volumes of a combustible mixture of fire-damp and air are present to produce that *primary force* which we have described, that coal-dust can become a powerful agent of destruction.

The passage of the flame from the point of ignition is not instantaneous; on the contrary, a sensible period expires before the explosion is complete, and it would be quite possible for the eye to follow the progress of the flame if it could be viewed through a transparent material.

We have already shown that the products of combustion generated during an explosion in a coal mine are much more complex than is usually credited, and the method adopted in some works on 'Mining' of tabulating those products is one which will not convey a correct idea of the reaction which takes place. When an explosion commences in a mixture nearly on the point of becoming inexplosive, owing to excess of air, and it does not encounter more concentrated mixtures, the effect produced is rarely very destructive either to life or property. It is when a large body of gas has become mixed with air that the result of an explosion becomes serious, more especially when towards that body a supply is continually moving so that mixtures of air and gas will be found in every proportion, some of which are inexplosive at ordinary temperature and pressure, owing to the presence of too much fire-damp, and some inexplosive owing to the absence of sufficient fire-damp, while a large body is composed of a mixture of fire-damp with nine and ten parts of air.

If the explosion commences in a large body of a mixture containing less air than is sufficient for complete combustion, the results and resulting products are likely to be very fatal; the products of combustion are of a peculiarly deadly character, while, as the explosion proceeds, the more concentrated mixture is forced onwards and meets with a more dilute one, and the consequence is that a compressed and terrifically powerful mixture is fired, which compresses the next portions of the gallery atmosphere with redoubled force and energy until the whole near that point is one living mass of flame. Fortunately, the effect of the explosive force in driving everything before it becomes lost immediately the flame dies out; and as the high-pressure steam generated during the explosion (from the hydrogen of the marsh-gas forming water with the oxygen of the mixture), and the heated gases become [illegible] and cooled, a backward suction [illegible] ence of the partial vacuum formed in the 'field' of the explosion, and some air finds its way into the workings. Were it not for this, much more loss of life would ensue, as the unfortunate miners situated out of the reach of the fire of the explosion would be overcome by the after-damp, and that, too, without chance of escape.

Owing to the oxygen consumed by the coal-dust floating in the air, and that raised by the explosive force, there will be very little left even at the point where the explosion terminates through the absence of sufficient combustible matter, and, as we have shown, that point will be very considerably in advance of what has been hitherto believed, on account of the influence which the *pressure* exerts upon the combustion of mixtures of air and fire-damp which are inexplosive at the ordinary pressure of the atmosphere. With regard to the gases generated during an explosion see paper 'On Afterdamp,' &c., in Appendix.

In order to afford some idea of the reaction which takes place during an explosion we will, for the purpose of illustration, divide the 'field' (by which term is meant the galleries, headings, &c., in which the explosion happens) of the explosion into three portions, A, B, and C, where A is that portion of the field occupied by a mixture of marsh-gas or fire-damp with ten parts of air; B is that portion where the fire-damp is mixed with less than ten parts of air; C is that portion where the fire-damp is mixed with more than ten parts of air. Let us suppose the explosive mixture is ignited at A, the consequence would be that the explosion would commence with tremendous force, which would continue without intermission throughout a large portion of C, and in like manner throughout a portion of B. Throughout the portion of the 'field' occupied by A the intense heat, destructive force, and the resulting products of combustion would leave no chance of escape to any of the miners who might be working there. Toward the exterior portion of C neither the high temperature nor force of the explosion would be of long duration, and the products of combustion would be drawn inwards when the backward suction commenced, so that if the direction of the 'return' should be in their favour many of the occupants of this portion of the field might escape. Throughout B there will be little mercy for the ill-fated miners who may be confined there; when the mixture contains most air the fire and explosive force will effectually assist in the deadly work of the after-damp, and where the less air is and the most marsh-gas, so deadly will the products of combustion, or, rather, the products of imperfect combustion, be that, in many instances, death will actually overtake the victim before he has become aware of the danger—in fact, a terrific hurricane, as it were, approaches him unheard and unsuspected, and one breath of the unmerciful atmosphere either kills him instantly or he as quickly passes into a state of coma, never to wake again.

In numerous instances, bodies have been recovered after explosions which appear to have suffered no injury whatever, and which have been found in most natural positions, and in some cases the expression of the countenance of the victim was that of pleasure, and not, as one would expect, of fear and intense anxiety. It is immediately outside that part of the field of the explosion occupied by B where the miners killed under the circumstances noted are doubtless found. Here (at B) not one atom of oxygen escapes combustion, and what was present becomes converted into that poisonous gas—carbonic oxide.

At A the products of combustion would be, for the most part, carbonic acid and water; at C they would be almost entirely carbonic acid and water; but at B they would consist of carbonic acid, carbonic oxide, hydrogen and water. From some recent experiments of the author it appears that carbonic oxide would be generated at A and C, owing to the presence of coal-dust; and if a cloud of coal-dust were raised, as is frequently the case, carbonic oxide would be largely formed and this gas would consequently render the after-damp very poisonous in cases where the force of the explosion was anything but formidable. In the latter instance, as also to a certain extent in all instances, there will be more or less smoke present after an explosion.

Explosion on board Ship.

Explosions on board ship are caused by the ignition of combustible gases mixed with air, and those which happen most frequently are similar in every way—on a small scale—to those dire calamities to which fiery coal-mines are apparently heirs to. When explosions occur on board ship in dock, or shortly after leaving the same, the results are entirely due to the enclosed gas becoming liberated from the coal, and giving rise to an explosive mixture by its diffusion through atmospheric air, and the subsequent ignition of this mixture by accident or other cause.

Explosions which have happened in the holds of vessels after having left port for a considerable time, were also caused by the ignition of gaseous mixtures; but it cannot be said that they were brought about by reason of the gases which were *enclosed* in the coal, especially in cases where the explosion was the forerunner of active spontaneous combustion. Such explosions, in the majority of instances, are due to the gases which are generated from coal when subjected to destructive distillation at a high temperature, or, in other words, they are due to the ignition of a mixture of coal-gas and air, and not to the ignition of a mixture of fire-damp and air.

We have frequently noticed in the reports of Board of Trade inquiries bearing upon explosions on board ship, that the main questions were directed for the purpose of learning the character of the coal in reference to sulphur, and the proneness of the fuel to undergo spontaneous combustion. It did not matter, apparently, whether the explosion took place at sea, or in dock; or whether the coal had been shipped one day, or two months, the same questions were asked, as if all explosions on board ship were brought about by one and the same agency. Now it will become evident, on carefully noticing what transpires before spontaneous combustion takes place in a cargo of coal (see next chapter), that there is little connection between the circumstances which give rise to explosions which happen in consequence, and those which are simply brought about through the agency of the gas enclosed in coal.

When a cargo of coal is being shipped, a large portion of it comes direct from the colliery, and is tipped at once—by night as well as by day—into the hold of the vessel. The admirable arrangements now furnished for the purpose of facilitating the shipment of coal, and the peculiar manner in which the vessels are made to self-stow, leads to the introduction of huge heaps of coal into a ship's hold within the space of a few hours. In many instances it happens, either through the carelessness, or ignorance of danger on the part of the ship's officers, that proper provision has not been made for the purpose of ensuring the removal of the fire-damp evolved from the coal as quickly as it is given off, and, not unfrequently, the hatches are put on within a day or two after the coal is shipped. All coal from fiery-mines, particularly steam coal, holds a large volume of enclosed gas (see papers in the Appendix) which continues to be evolved for several days after the coal is stowed. The light character of marsh-gas admits of its easy removal by surface ventilation, so as to prevent the accumulation of an explosive mixture, provided ordinary precautions are taken, and the hatches are left open as long as possible, or until the vessel gets into the open sea if the weather permits.

If these precautions are neglected, and the hatches are put on shortly after the coal is stowed, the consequence is that there is not sufficient ventilation to carry off the gases evolved, which diffuse through the air in the hold of the vessel and form an explosive mixture. This mixture gradually finds its way to adjacent parts of the ship, where it may become ignited, or, as sometimes happens, one of the crew or the men who stowed the coal have reason to descend into the hold, and, heedless, or unaware of the danger, take a naked light with them. The result is that a powerful explosion takes place, attended with considerable destruction of life and property.

In conducting any inquiry into the origin of an explosion of this kind, the points to be considered are:—1. Does the coal contain a large volume of enclosed gas, and does it evolve gas rapidly? The hardness and porosity of the coal have much to do with this.

2. The time which expired during the loading of the vessel, and the time which elapsed after the coal was shipped previous to the explosion. The answers to 1 and 2 will be the means of throwing much light upon 3 and 4.

3. Did the shippers of the coal inform the owner, or master of the vessel, that the coal was a gaseous one, and lose no opportunity of pointing out the danger of not attending to the ventilation of the cargo?

4. Did the officers of the vessel use all the means at their command in order to ventilate the cargo, and see that the hatches were not put on in the dock or harbour?

If proper precautions be taken to ventilate a cargo for some time after it is shipped, there will be no danger of an explosion happening at any subsequent period through the agency of the gas enclosed in the coal, for the following reason. Each succeeding day after the coal is [illegible] from the mine, the quantity of gas evo[illegible]s and less, and, in addition to this, the percentage of carbonic acid which it contains rises higher and higher, until, after a time, the gases given off cease to form an explosive mixture with air, in consequence of the high percentage of carbonic acid present.

When the ventilation has been deficient, and oxidation of the coal begins, the temperature of the mass rises, and it sometimes occurs that it continues to rise until the point is attained at which some of the gases—generated by the effect of the heat upon the coal—take fire, and an explosion happens. This is brought about by the heat incidental upon the oxidation of the coal, and the destructive distillation which ensues—a process which is, however, one extending over a great number of days; and an inquiry into the circumstances which have given rise to the same is attended with far greater difficulty than that having reference to the ignition of an explosive mixture of air with the *enclosed* gas of coal. (See 'Spontaneous Combustion of Coal.')

CHAPTER X.

COMBUSTION—SPONTANEOUS COMBUSTION ON BOARD SHIP—ABSOLUTE THERMAL EFFECT OR HEAT EVOLVED DURING COMBUSTION — DYNAMICAL THEORY OF HEAT—NATURE OF FLAME—RESPIRATION.

By the term combustion is meant, usually, the burning of some material or body in air; chemically speaking, the word includes all those phenomena incidental upon the production of heat and light through either chemical combination or decomposition. It is, however, only in the sense in which the term is commonly used and without strict adherence to scientific principles that we shall apply it in the present instance.

When a piece of coal is ignited by a red hot body it is said to undergo combustion, and according to the readiness with which it can obtain a supply of the element oxygen the process will be complete or only partial. The combustion of different materials or bodies is dependent upon several conditions, such as the temperature of ignition, the size or mass of the igniting body, the size of the body to be ignited, the nature of the material upon which the body to be ignited is lai [illegible] ee of inflammability, &c.

Some c [illegible] bodies — artificially prepared, of course—undergo spontaneous combustion at the ordinary temperature of the atmosphere, and can only be preserved in sealed tubes. Phosphorus and sulphur ignite at a comparatively low temperature, while the majority of the elements require either an elevated temperature or undergo combustion only at extreme temperatures. Iron enters into active combustion only at a white heat. Hydrogen and carbonic oxide can be ignited by an iron wire $\frac{1}{40}$ of an inch thick at a red heat, but Sir H. Davy found that marsh-gas cannot be ignited by a wire $\frac{1}{40}$ of an inch thick at a white heat.

As we have already observed, much depends upon the condition of the body to be ignited, and when in the gaseous state the igniting point becomes higher when the combustible gas is largely diluted with air, and this is so whether the mixture is compressed or not. A large body of intense heat will determine the combustion of gaseous mixtures which are uninflammable at the ordinary temperature and pressure of the atmosphere when the igniting body, although at a high temperature, is of small mass.

The combustion of gases at a low temperature is much assisted by the presence of some metals and substances in a very finely comminuted condition. Spongy platinum and platinum black determine the combination of hydrogen, carbonic oxide, and marsh-gas with oxygen, even when largely diluted with air. This, however, depends upon the operation of a peculiar mechanical force, which appears to act only upon the surface of the interstitial spaces.

If any substance or material has been ignited, and placed on a surface sufficiently cold to absorb the heat faster than it is generated, the ignited body will soon go out; for instance, a live coal placed on a plate of iron soon dies out, because the iron plate and surrounding air abstract or absorb the heat until it falls below the point of ignition.

Gases, when mixed either with air or oxygen, cannot, as Sir H. Davy has shown, be ignited in fine capillary tubes, even if one end be held in the fire. This is owing to the cooling effect of the sides of the tube, which absorb the heat so rapidly that the gas is not allowed to rise in temperature sufficiently high to undergo combustion. The author found that marsh-gas, mixed with twice its volume of oxygen, cannot be ignited by the electric spark in a tube $\frac{4}{5}$ of an inch (20mm.) in diameter when rarefied or expanded eight times, or hydrogen gas mixed in a similar tube with half its volume of oxygen when rarefied seven times, or hydride of ethyl with three and a half times its volume of oxygen under like conditions when rarefied eight times.

Some of the elements are capable of existing in combination with oxygen under two or more conditions, embracing the products of complete and incomplete combustion, but only two are described in this treatise, viz., carbon and sulphur.

Incomplete combustion implies the burning of a substance, element, gas, or liquid, in a smaller volume of air than would be sufficient to convert it into the highest state of oxidation which its constituent elements are capab[illegible] assuming.

By complete [illegible] is meant, therefore, the combinatio[illegible] body—gaseous, liquid, or solid [illegible] as will convert all the elements concerned into the highest state of oxidation which they assume by burning in an unlimited supply of atmospheric air.

Hydrogen combines in burning with only one equivalent of oxygen, and therefore forms no product of incomplete combustion. Carbon, in the presence of a limited supply of oxygen, forms carbonic oxide, which is the incomplete product of the combustion of carbon :—carbonic acid or dioxide being the complete product. Sulphur dioxide may be regarded as the incomplete product, and sulphur trioxide (sulphuric anhydride) as the complete product of the combustion or oxidation of sulphur. In the absence of sufficient oxygen in a gaseous mixture to consume all the hydrogen present, all the former gas combines with the latter to form water, while the excess of hydrogen remains intact. A mixture of oxygen and hydrogen in the proportion to form water (electrolytic gas) will not explode when mixed with less than half its volume of marsh-gas, hydride of ethyl, or olefiant gas.

Spontaneous Combustion of Coal on board Ship.

The oxidation of various substances is regarded as, and practically is, a slow combustion. Some compounds containing carbon, hydrogen, oxygen, and nitrogen, oxidise and undergo decomposition at the ordinary temperature, and if present in considerable mass, they not unfrequently generate sufficient heat to start active combustion, or undergo what is commonly termed spontaneous combustion. This is due to the active dissociation and breaking up of heavy organic compounds, accompanied by the resolution and combination of their elements in other forms, with the formation of other compounds chiefly of a gaseous character. Nitrogenous compounds, and vegetable compounds which have only recently lost their vitality, are most prone to undergo these changes.

There are many materials, such as cotton waste when oiled, freshly burnt charcoal, and some coals in a finely comminuted condition, liable to undergo spontaneous combustion. The more finely divided the particles of a body are, the more rapidly will it undergo oxidation, and if there is a mass of the finely divided matter, it may oxidise so rapidly and generate so much heat as ultimately to take fire. This sometimes happens in collieries through the oxidation of coal in fine slack or powder, but spontaneous combustion is mostly confined to those collieries where the coal is of a highly bituminous character, and one containing a very appreciable percentage of combined oxygen. Combined oxygen assists materially in rendering the oxidation of the finely divided coal very active, and the oxidation proceeds so rapidly that the temperature of the mass becomes hotter and hotter, until it reaches the point of ignition, and combustion, rightly so called, commences. The coals of the Staffordshire coal-field are some of the most liable to undergo spontaneous combustion when in the state of fine powder. We have already referred to this on page 60.

With regard to the spontaneous combustion of coal on board ship, very little evidence which is calculated to throw light upon this important subject has [illegible] ently, and our knowledge upon this matter is, we fear, likely to remain imperfect for some time to come. The proof of this is shown in the fact that very little was elicited by the last Commission, and the paper drawn up by Dr. Percy and Professor Abel, although a most interesting and valuable collection of facts, contains, however, little that is new. The spontaneous combustion of coal on board ship was at one time, and is now to a very great extent, supposed to be due to the oxidation of pyrites which coal contains. This idea was strengthened by the fact that alum schist—which contains much pyrites—undergoes oxidation very rapidly in the presence of moisture and atmospheric air, and advantage of this has been taken for the purpose of manufacturing alum.

As before noticed, all coal contains sulphur in some combined form, and probably too in some instances in the free condition; but in the case of coals which are of sufficiently good quality for export to foreign countries, entailing long voyages, it may be safely said that the sulphur exists in them only in the state of bisulphide of iron FeS_2:—at any rate sulphur has not yet been found in organic combination in any coal which has undergone spontaneous combustion during a voyage however long.

Dr. Percy[1] does not attach much importance to the presence of pyrites as the exciting cause, although it is strongly alluded to in the paper to which we have referred. In the presence of moisture and air pyrites sometimes oxidises very rapidly, and in some instances under inexplicable conditions, while in others it exhibits curiously stable properties. As a rule, however, pyritic coal is not the subject of spontaneous combustion on board ship, because the mere fact of a coal containing much pyrites indicates that it is of little value in a commercial point of view, and it is only the better class of coal which is selected. In some rare instances, it may be that cargoes have been shipped which contained a very appreciable quantity of pyrites, because it is present in some of the best seams of coal in laminated veins between shale or top divisions or layers; and in seasons of briskness in the coal trade—which unfortunately is not at the present time—and through the negligence of proper supervision pyritic coal may become shipped.

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[1] Percy's *Metallurgy*, vol. i. p. 299. 'Fuel,' etc.

Richter has shown that those coals which most readily undergo oxidation, and enter into spontaneous combustion in the state of fine powder, are not in the majority of instances those which contain the most pyrites, and as a natural consequence it is not probable that the oxidation of pyrites is the exciting cause of the spontaneous combustion of coal on board ship, although it assists in the further production of heat, and undergoes oxidation in company with the coal itself.

The fact that the more anthracitic coals, exclusive of the percentage of sulphur which they contain, are less liable to undergo spontaneous combustion than the more bituminous, throws some light upon the subject, and it is evident that the bituminous character of the coal has a great deal to do with it. We have already remarked in reference to the state of division of different ma [illegible] nd the greater liability of substances t [illegible] on when in a highly comminuted condition. Coal in the state of fine powder offers a very large surface for oxidation, and all the absorbing influence is brought into play at the same time. Substances which possess the property of absorbing gases—such as charcoal for instance—do so with great rapidity, and the velocity of the gases traversing fine capillary channels forming the pores of the material, gives rise to so much friction that the force is converted into heat, and on this account it is that porous charcoal like that made from willow and alder wood, when turned out of the carbonising retorts is liable to enter into spontaneous combustion. It is not owing to the great oxidability of the charcoal, for it is a most stable body and remains unaltered in the air for long periods of time, but by reason of the absorbing action, which is for the most part mechanical, and the heat generated in consequence. It must be admitted that the great porosity and minuteness of division and combustible properties of charcoal, render it more liable to spontaneous combustion than any other material containing so much carbon.

Were it not for these considerations, the remarks which we have made respecting the liability of the more bituminous coals, and the non-liability of the more anthracitic, to undergo spontaneous combustion would not hold good. Setting aside charcoal for the reasons stated, there is no highly carbonised compound like coke or anthracite, which is prone to active oxidation or spontaneous combustion.

One would naturally anticipate that the more oxidisable portion of coal would have been destroyed previous to the organic material, from which coal is produced, becoming buried under any appreciable thickness of 'top,' and doubtless this was so, to a very great extent; but after the lapse of ages, the subsequent breaking up of some nitrogenous or other compound containing hydrogen may have given rise to some partially volatile compound, readily oxidisable.

Organic matter which has been subjected to partial decomposition or destructive distillation, out of contact with the air, possesses, for the most part, the property of condensing gases, or of showing an active oxidation peculiar to itself. Some iron compounds containing organic acids, after ignition in sealed tubes—with the consequent breaking up of the organic acid—leave the iron in a very finely divided state, and when it comes in contact with the atmosphere, so rapidly does it absorb oxygen that the mass enters into rapid combustion. Tartrate of lead ignited in a tube leaves a porous mass which takes fire when it comes in contact with the air.

The bituminous kinds of coal, and not unfrequently the free burning hydrogenised varieties, which contain very little oxygen, hold enclosed in their mass volatile oxidisable matters which escape from the coal or rapidly undergo oxidation when piled in large heaps. It is to these bituminous or volatile hydrocarbon matters containing oxygen, that the primary action of starting oxidation is due, and, as soon as a moderate heat is generated, more or less of the whole mass of coal takes part, and generates further heat, until the igniting point may be attained. It will be found, too, that the coals which are liable to spontaneous combustion on board ship possess the property of enclosing oxygen, or, in other words, of absorbing air by the displacement of their enclosed gases; and the author found in two instances that the small or dust portions of such coal, after exposure to the air, contained an abnormally large proportion of combined oxygen. We have already referred to Richter's experiments in this direction, and pointed out the possibility of the carbonic acid, which he attributed to oxidation, being present in the coal as enclosed gas.

Richter's and Reder's experiments show that when coal has been exposed for twelve months in a heap, provided there has been no rise in temperature in the mass, it suffers no appreciable change; this has been the experience of the author also, but at the same time the foregoing remarks do not agree with Richter's further determinations, from which he concludes that coal absorbs, at the ordinary temperature, a considerable quantity of oxygen, some of which oxidises the carbon to carbonic acid, and the remainder enters into combination with the mass of the coal and forms a fixed oxygenated compound.

It will be seen, however, from the results of the experiments of Dr. Von Meyer and the author which are tabulated on pages 34–47, that coal on weathering does not contain an abnormal percentage of oxygen in the enclosed gases, and the experiments referred to show invariably that the oxygen has simply entered the coal by diffusion in company with nitrogen as air. Richter experimented with lignite, which is of a much less stable character than carboniferous coals.

In the paper already alluded to, Dr. Percy and Professor Abel state that 'spontaneous oxidation of coal by the oxygen absorbed from the air is therefore satisfactorily established, and is unquestionably one, if not the chief cause, of the spontaneous heating of coal.' This conclusion is apt to mislead the reader, and really is not intended to convey all that may be deduced from it. The mere fact of lignite undergoing spontaneous oxidation—a fact which we do not question—does not prove for a moment that all coals are thus influenced. We think it will be found that the majority of steam and anthracite coals are not readily oxidised, and, indeed, we go so far as to state that at the ordinary temperature of the atmosphere the amount of oxidation is very insignificant in any coals of carboniferous age—such as those of the North of England and South Wales coal-fields.

When, however, coal dust, minutely comminuted, has become deposited in some quantity, or the temperature of a large mass of coal is raised, then oxidation takes place rapidly; it is, in fact, when the temperature becomes raised—no matter by what means—that oxidation proceeds, and the only problem we think which requires to be solved is by what means coal becomes heated in the hold of a ship, and by what means can such heating be prevented?

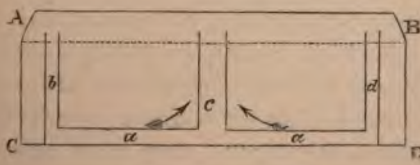
The presence of pyrites and its influence has been previously mentioned, but pyrites will not account for the many accidents which have happened in consequence of the spontaneous combustion of coal which contained it in minute quantity only. We are not prepared to solve the problem, but simply make the following remarks and suggestions. All coal contains a certain proportion of water or moisture, in quantity mostly in excess of that which was present in the seam or vein, and organic matters when stacked in large bulk in a slightly moist condition undergo a kind of *sweating* action with the formation of heat, during which the oxy-compounds in the coal become partially dissociated or decomposed. If the coal is a porous one oxidation proceeds, and according to the amount of air which permeates the bulk, and the time which expires from the period the coal is shipped until the vessel goes to sea, together with the character of the coal, and the length of the voyage, the temperature of the mass may continue to rise or gradually cool down. It is possible that the time which expires from the loading until the ship commences the voyage is a very important consideration, because the rolling motion of the ship continually produces fine dust by attrition, and continually liberates traces of oxidisable matters pent up in the pores, and brings the bulk of the coal into a condition calculated to retain the heat generated. Again, the amount of combined oxygen is another important item which possibly exercises considerable influence.

If the temperature of the mass could be kept down during the *sweat*, and until the small quantity of volatile matters had undergone oxidation, there would be little fear of spontaneous combustion occurring after. A lump of coal, or coal stacked in small quantity, does not ferment or oxidise to any perceptible extent. The action of the atmosphere upon some coals is peculiar, and is regarded by many with a strong suspicion that it deteriorates rapidly. This is owing to the fact that coal loses much of its gases, and also the traces of volatile matters which it contains, and in many instances its property of caking; but its chemical composition is not perceptibly altered for a considerable time. These remarks have no reference to lignite, but to true carboniferous coals only.

In the paper by Dr. Percy and Professor Abel, to which we have alluded, it is stated that 'they are of opinion that ventilation through the cargo would not have the effect of preventing spontaneous combustion.' We quote the following passage. 'As regards the application of ventilation with a view to reduce the liability to spontaneous *ignition* of a cargo of coal, the only useful object which could *possibly* be aimed at by ventilation would be the rapid abstraction of heat developed in the coal, by causing cool air to circulate freely and rapidly throughout the *body* of a mass of coal. The attainment of such a result, even by powerful means of artificial ventilation, elaborately applied, and with the coal in the mechanical condition most favourable to its free permeation by air, appears, to say the least, very doubtful, and there can be no question that any system of ventilation, practically applicable on board ship, would fail to attain such a result, even disregarding the fact that the mechanically finely-divided condition of much of the coal constituting a cargo is quite antagonistic to the free passage of air through its mass.' After mentioning the difficulty of ventilating, they further state that it is not practicable to ventilate a cargo, while if heat had accumulated the presence of fresh oxygen would enliven oxidation.

To the latter portion we entirely agree, and if considerable heat is generated, ventilation would only act as fuel or assist oxidation, but we urge that ventilation well applied in the first instance would prevent further heat. In the agricultural world it is well known that when hay is stacked in large ricks in a somewhat green and moist condition, the temperature of the mass rises—the aqueous portion being driven off as steam—after the lapse of some days, or weeks, or even months, according to the bulk of the mass, and the conditions at the time of stacking, the temperature continues to rise and eventually the hay-rick takes fire.

The sweating of coal to which we have referred starts probably on the same principle. The author has on several occasions tried the effect of ventilating hay and corn ricks or stacks, and invariably found that when the weather was unpropitious for harvest it was quite possible to stack crops in a somewhat green condition, and in a condition, too, that, had no ventilation been afforded, spontaneous combustion would certainly have taken place. The ventilation, which was entirely self-dependent, was done thus:—Let A B C D represent a vertical section of a hay-rick.



On the ground a wooden launder or pipe *a a* from 10 to 16 inches square, having the top perforated, is laid from about 2 yards to the right of C, and continued to within about 2 yards to the left of D. *b*, *c*, *d* are three upright square pipes perforated on all sides, *c* being twice the area of *b* and *d*. When the temperature rises in the rick, a self-acting current is generated in the direction of the arrows, which becomes stronger according as the temperature rises, owing to the heat being greater in the centre than near the ends, and the centre pipe may, therefore, be likened to the upcast shaft of a coal mine. With such an arrangement there is not the slightest fear of a rick taking fire, no matter in what condition the hay is stacked, and, be it remarked, the porosity of a cargo of coal, and its conformation to air-currents would be superior to that of heated hay—a cargo of coal would be, in fact, much more permeable to air than heated hay. As shown, the wooden pipes are not carried through the rick, because under the thatch the hay remains soft, and air can circulate; but in the hold of a vessel, the coal could be ventilated on a somewhat similar principle, only it would be better to carry the ventilating tubes through the deck, and have the centre one in connection with a fan worked by a windmill or other contrivance.

If by some such arrangement, a cargo of coal was thoroughly ventilated for the first week after the coal was shipped, there would, we think, be little risk of spontaneous combustion occurring afterwards, provided the coal had an air-course at or near the bottom of the cargo. During the first week after the coal was shipped, there would be much better chance to ventilate it effectually than afterwards, as it would not have settled sufficiently close to offer much resistance to air passing through the mass. If the coal is already heated and it has been stowed some time, there will be far greater difficulty experienced in cooling it, and, as before stated, fresh air will so aid in the production of heat by oxidation, that the cooling effect of the ventilating current would be overbalanced. We think it probable that the presence of moisture in coal starts an incipient fermentation, and that the heat generated could be removed, and the excess of moisture too, by the aid of active *through* ventilation applied *as soon* as the coal is stowed, so as to prevent further heat being generated by oxidation, and consequently obviate any subsequent risk of spontaneous combustion occurring. The presence of water in the hold of a ship would not assist oxidation, or start the fermentative action we have alluded to, but the deposition of dew upon coal in trucks (shipped) at night, or the moistening of coal by rain, is very probably the prime mover or cause of the generation of heat.

Absolute Thermal Effect, or Total Heat of Combustion.

The total heat evolved by burning various substances in oxygen, has been determined by Andrews, and by Favré and Silbermann. From their experiments the number of heat units [1] evolved by burning one gramme of the following elements and compounds in oxygen is :—

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[1] *Heat units* represent the number of grammes (15·432 grains) of water which can be raised in temperature 1° C. (1·8° F.) by burning one gramme (15·432 grains) of a substance in oxygen.

Carbon (diamond)	7770	Favré and Silbermann
Wood Charcoal	7900	Andrews
" "	8080	Favré and Silbermann
Sulphur (flowers of)	2307	Andrews
Hydrogen	33881	"
"	34462	Favré and Silbermann
Marsh-gas	13108	Andrews
"	13063	Favré and Silbermann
Olefiant gas	11858	" "
" "	11942	Andrews

The total heat, or absolute thermal effect of hydrogen is about 4½ times greater than that of carbon. Taking carbon as unity, the ratio of the heat evolved by the combustion of equal weights of the following will be:—

Carbon	1·00
Sulphur	·28
Hydrogen	4·44
Marsh-gas	1·69
Olefiant gas	1·52

The absolute thermal effect of wood charcoal, according to the above, would be more than that of carbon,but this seems improbable, and is possibly (if free from hydrogen) about ·96, taking carbon as 1·00.

With the exception of olefiant gas, the heat evolved during the combustion of compound substances, is less than that of the sum of the elements of which they are composed. The experiments of Scheurer-Kestner and Meunier upon the calorific power of coal show, however, that with coal this is not the case, and they found that the experimental heating power of coal was greater than the theoretical value of the constituent elements. It will be observed that the determination of wood charcoal by Andrews, and by Favré and Silbermann, is higher than that of the diamond, and this may be due to its containing some combined compounds, notwithstanding its purification in a current of chlorine:—in any case some ash must have remained, and the numbers although doubtless correct—appear high.

Dynamical Theory of Heat.

The amount of heat which is apparently lost in converting solid bodies into liquids and liquids into vapours was long known as *latent heat*. When ice is in the act of being melted by heated water, the temperature does not rise until the whole has been liquefied; the heat applied being absorbed by the ice at the moment of its becoming a liquid in such a manner as to be insensible; and this absorption of heat was termed the *latent heat of fluidity*. It is well known that a very considerable quantity of heat is seemingly lost, or, as once expressed, rendered *latent* when water is vapourised, and that much of the equivalent of this heat is obtained when steam condenses. The temperature of steam under ordinary atmospheric pressure is the same as that of boiling water, 212° F., and if we add a volume of boiling water to an equal volume of water at 100° F., the temperature will be the mean of the two volumes, viz., 156°. But if the water at 212° be converted into steam, and the vapour passed into the water at 100°, the latter will boil before much of the former is changed into steam. This was formerly explained by saying that a liquid in the act of vapourising, takes up or absorbs heat in an insensible form, and that it gives up its *latent heat of evaporation*—as it was termed—when the vapour condenses or assumes the liquid condition.

According to the *latent heat* theory, it was necessary to recognise heat as having a definite existence, or, in other words, as being present or stored up in bodies without in any way increasing their weight. The modern view of the nature of heat is, that it is a state of matter dependent upon molecular motion, or, according to Tyndall, '*a motion of its ultimate particles.*' The particles of bodies are said to be in constant motion. So far as the gases are concerned, we can readily understand that this may be a fact, but it is more difficult to conceive that the particles of a solid, or their constituent atoms, move, although it is possible they may.

The atoms of a gas are supposed to be arranged in molecules, which contain a number of atoms associated together, and these molecules come in contact with each other, and are in constant motion, moving forward in straight lines, although they may undergo rotatory and undulatory movements as well, and their constituent atoms may vibrate by reason of the impact of the molecules.

Because the molecules of a gas are in constant motion heat is generated, and the more rapidly the molecules move the higher will be the temperature of the gas, in fact the rate of motion of the molecules of a gas determines its actual temperature.

When a force is brought to bear upon matter so as to interfere with the internal movements of its molecules the temperature lowers, and the temperature of a body rises when any power is exerted in a manner which will add to the rapidity of molecular motion. When, therefore, water is converted into steam it is inferred that the power of the heat applied acts in a direction opposed to the ordinary molecular forces, and that the production of heat incidental to the natural force of progressive motion is prevented. As soon as the opposing energy (the heat which maintains water in the state of vapour) is removed and the steam condenses, the molecules, and possibly their constituent atoms, re-arrange themselves, and in doing this the velocity of the progressive motion becomes so much greater, or, in other words, so much work is done that considerable heat is generated. When water is vaporised the external pressure of the atmosphere has to be overcome—a cubic inch of water occupies about a cubic foot in the form of steam—so that much of the power or heat which is apparently lost in vaporising a liquid is used up in overcoming atmospheric resistance; but the pressure of the atmosphere will be available for producing motion, which will give rise to heat, when the vapour liquefies, in consequence of the great decrease in volume which results.

The expansion in volume which a solid undergoes in liquefying is not considerable, and, consequently the external resistances which have to be surmounted are not great, but the internal work of disarranging the molecules of a solid requires the expenditure of much power. The molecules of a solid are supposed to oscillate about certain positions of equilibrium which are definite and unalterable, unless acted upon by external forces. The peculiarly crystalline condition which the best malleable iron assumes when subjected to vibration in moving machinery, seems to show the possibility of the molecules of a solid permanently altering their positions under the influence of extraneous forces.

In the liquid state the molecules are not perpetually associated with each other, as in solids uninfluenced by outward force, but may alter their positions, possibly, and rotate about their centres of gravity, and undergo vibratory movements in other directions: always regulated, however, by mutual attraction, which is never counterbalanced by the repulsive action incidental to the motion of the molecules.

The dynamical theory of heat has developed into a distinct branch of physical science, since the mechanical equivalent has been quantitatively determined, but the limits of this Treatise will not admit of entering into much detail.

The mechanical equivalent of heat, as found experimentally by Joule, may be expressed thus:—a mechanical force represented by the fall of 772 lbs. through the space of one foot, is equivalent to the quantity of heat required to increase the temperature of one pound of water by 1° F.

Nature of Flame.

Those bodies which are converted into gas in the act of undergoing combustion burn with a flame which may be luminous, or only partially so, according to the nature of the matter consumed. Compounds or elements which do not pass into the gaseous condition on burning cannot be said to flame, the heat and light generated being exhibited simply as incandescence. The flame of a candle is due to the tallow being converted into gaseous products by dissociation and incomplete combustion, owing to the absence of sufficient air. The flame of a candle consists of four distinct portions, a lower ring, which melts the tallow and meets with a current of cool air from below, the combustion here being complete for about one-eighth of an inch inwards. Around the wick and for some distance upwards there is a non-luminous cone, usually of a bluish colour; this is the zone of incomplete combustion, where the tallow is partly oxidised and broken up into hydro-carbon compounds of lesser density, which rise upward into the white portion of the flame, and become intensely heated, emitting the greater portion of the light given by the candle. The combustion at this point is not complete, and if any cold body is held in the luminous cone, as it is termed, soot is deposited. On this account it is thought that the hydrocarbon compounds are partially consumed, and that some of the carbon is separated, and becomes highly incandescent, and gives rise to the light. Dr. Frankland regards the luminosity as due to the vapour of heavy hydrocarbons, and that light is not dependent upon solid particles of carbon being present in the flame. Much might be said in support of either theory, but it would be out of place to enlarge upon it here. If ethyl is exploded in a tube with five volumes of oxygen, a very large proportion of finely divided carbon is deposited, and it is possible that the same reaction may take place in the luminous portion of a candle flame, as it is known that there is not sufficient oxygen present for complete combustion.

Hydrogen gas burns with a reddish flame, and carbonic oxide with a blue flame, neither of them being luminous. Marsh-gas, when pure, burns with a non-luminous flame, which becomes slightly luminous when coal-dust or traces of higher hydrocarbons are present in the gas. A luminous gas flame is rendered non-luminous by mixing air with it before burning. This is on account of the air supplying sufficient oxygen to convert the carbon of the hydrocarbons present in coal gas into carbonic oxide, and, as a consequence, no hydrocarbon is left which, by its vapour, or by the deposition of carbon, can give rise to luminosity in the flame. The Bunsen burner is on the principle for burning a mixture of air and coal gas, and gives a non-luminous flame, and if a cold body is held in any part of it no carbon is deposited, owing to the absence of heavy hydrocarbons.

Respiration.

By respiration is meant the act of affording, mechanically, a supply of oxygen for the purpose of oxidising the products of food in the blood so as to generate heat. In the animal kingdom, the lungs act as the carrier of oxygen mixed with nitrogen as air, and also play the part of driving off the air and oxidation products generated.

The taking in of air is called *inspiration*, and the expulsion of that used for oxidation is called *expiration*. The muscles between the ribs and diaphragm determine inspiration and expiration by extending or compressing the lungs, which are cellular sacs thickly netted with minute blood-vessels, and capable of holding appreciable volumes of air, which is brought in contact with the moist blood-vessels, and the oxygen passes partly in the state of loose combination into the blood, in order to oxidise the matters dissolved therein, and to generate, by chemical combination, the heat necessary to the support of animal life. In this manner the carbon and hydrogen of food are burnt, so to speak, by a process of slow combustion or oxidation, and converted into carbonic acid and water.

The percentage quantity of carbonic acid generated and expired is dependent upon several conditions, such as the age and sex of the individual, the exertion which is undergone, and is much less during sleep than at any other time. The quantity of carbonic acid in breath has been determined by a great many observers, and the results differ, naturally, very considerably, some of them being as low as 3 per cent., and others as high as 7·5 per cent.

If the breath is held as long as possible before expiration, the quantity of carbonic acid is increased, and by accelerating the number of inspirations it is generally decreased. Less carbonic acid is exhaled in the summer than in the winter. It is probable that a man undergoing active exertion, such as a collier, for instance, exhales about five parts of carbonic acid out of every 100 parts expired during the period which he is at work. Persons confined in warm rooms do not generate carbonic acid in so large a quantity as those whose occupation is in the open atmosphere. The proportion of carbonic acid in breath increases slightly after partaking of a meal, and it is greater when the barometer is high than when it is low.

Taking the average quantity of air exhaled by a collier as 22 cubic feet per hour, and the percentage of carbonic acid as 5, each collier will evolve in his breath, during eight hours, 8·8 cubic feet of carbonic acid, or 1·1 cubic foot per hour. Boussingalt found by experiment that a horse, moderately fed, consumed in respiration 79 ounces of carbon, which is equal to 155 cubic feet of carbonic acid per day per horse. A lamp gives off about 1½ cubic feet of carbonic acid for every ounce of oil burned. From the above data, therefore, it is easy to calculate approximately how many cubic feet of carbonic acid are generated by the respiration of the men and horses and the burning of the lamps in a coal mine.

With regard to the manner in which food is oxidised in the body, and how that oxidation is brought about, very little has been absolutely decided. It is fully known that carbon is oxidised in the body, and that heat is thereby generated, and that hydrogen also takes a part in the reaction, and becomes converted into water. Nitrogen in small quantity is also supposed to be set free. The hæmoglobin of blood, that is to say, the ferruginous portion known as the red corpuscles, are supposed to act in a manner analogous to spongy platinum, and to determine the oxidation and combination of the food products with the oxygen which finds its way into the blood. It is very possible that some such influence is brought into play, as the oxidation of the food material takes place much more rapidly than it otherwise would.

We have previously mentioned that, in addition to carbonic acid, there are other products evolved in breath which have very probably a much more deleterious action on the animal economy. We are somewhat in the dark regarding the nature of these matters, but it is evident that they undergo active decomposition very rapidly, and that they exercise a very depressing influence upon those who are compelled to re-inspire them. In crowded rooms and places of amusement the effects of inhaling the animal matters in breath are felt, and a peculiarly distressing condition of the body, entailing lassitude and stiffening, is experienced.

With regard to the quantity of carbonic acid which should be present in air fit for breathing, much depends upon the source from whence the carbonic acid comes: if it is derived entirely from the exhaled air or breath, on no account should it exceed 0·1 per cent., and any in excess of this shows, unmistakably, that the air is not breathable. In some mines, where the air-currents receive a supply of carbonic acid from the coal, this gas may be present in larger quantity. Pettenkofer states that air containing 1 per cent. of carbonic acid may be breathed for some time without experiencing any ill effects. Angus Smith[1] gives the result of a number of experiments upon the air in mines, and judges of the quality or fitness of the same for respiration by the percentage of oxygen which it contains. Dr. Smith examined nearly 400 samples of air from coal and metal mines, and the results of his experiments show very conclusively how necessary it is to furnish as much air as possible, in order to carry off the products of respiration and combustion. It appears that no less than 89 per cent. of the large number of samples examined were either impure or very bad, only 10·7 per cent. having nearly the normal percentage of oxygen. The average carbonic acid found by Dr. Smith was ·785 per cent., and in some instances it exceeded 2 per cent.: it is evident, therefore, that more ventilation was necessary, in order to render the products of respiration and combustion more dilute.

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[1] *Report on the Air in Mines.* London, 1864.

CHAPTER XI.

'VENTILATION'—THE EFFECT OF ATMOSPHERIC INFLUENCE ON.

THE term 'ventilation,' as generally applied, signifies, to give vent to, or afford an opening to, or admit through, or remove through, some opening. It is used to indicate and define a certain influence brought to bear upon a portion of the atmosphere which is in a state of partial confinement, or which is removed apart from the bulk of the atmosphere, so that the regulating phenomena of nature, in the form of air-currents and winds, are deprived, in a great measure, of their ordinary power. When air is confined so that it is entirely removed from the influence of air-currents, its particles mix and re-mix through one another at the rate of 'mutual diffusion' only. Now mutual diffusion, grand as is the law which regulates it, is somewhat slow in its action, but sufficiently fast, however, in the absence of retarding influence, to keep the atmosphere in a condition of pretty uniform admixture. When, however, influences, entirely foreign, are brought to bear upon this mutual or natural diffusive force, as when other gases are introduced into the atmosphere, and portions of it are heated unequally, and, as a natural consequence, rarefied by that heat, and, moreover, no outlet is afforded for the ready escape or intermixing of any confined portion of the atmosphere with the other mass, contamination ensues—the evenly balanced condition, the continuity of proportion of the oxygen, nitrogen, and carbonic acid is destroyed and broken, and the portion of the atmosphere under consideration is rendered so vitiated as to endanger the safety and health of human beings, who, by force of circumstances, may be compelled to inhale it for long periods of time. Such are the conditions when a number of persons are huddled together in a small bedroom, possessing only, nominally, a window and entrance door, without even an apology for a fireplace. In such instances, and it is to be regretted they are not a few, it frequently happens that the window sashes and the door fit in their frames with unfortunate accuracy, and, as a consequence, little air gains access to the room, and little air can make its exit from it.

A man breathes into his lungs ·35 of a cubic foot of air per minute, and of the quantity exhaled from 3·5 to 5 per cent. of the whole by volume consists of carbonic acid. In addition to this, the exhaled air is more or less saturated with aqueous vapour, containing animal matters given off by the blood and the skin, and conveyed outwards or expired with the air. These animal matters are not inspirable—that is to say, it is not conducive to health to re-inspire or breathe again the matters exhaled from the body; but apart from this, they are condensed on the walls, floor, and ceiling of the apartment, and there undergo decomposition, and are calculated to predispose the human subject to imbibe various forms of disease. Sanitary science is only just awakening from the lethargy in which it has reposed, with regard to the importance of these animal matters in breath, which, like other compounds rejected by the animal organism, are bearable and apparently harmless when freshly generated, but after they have undergone decomposition, they are resolved, probably, into various morbid forms, and it is difficult to conceive, or to estimate, in the present state of sanitary science, from the lack of data of a reliable nature, the evils which arise in consequence of their re-absorption into the animal economy.

The atmosphere in the room would become heated and rarefied by the increased temperature of the exhaled gases, which implies an increase in its bulk, so that a pressure would be exerted from within, outwards, and the chances of fresh air being introduced considerably lessened. In order, therefore, to combat against the evils which inevitably result, it is essentially necessary that some channel or outlet shall be furnished, whereby the vitiated atmosphere may escape and fresh air become admitted.

As soon as air is rarefied, the laws which govern its diffusion are altered or impaired, as well as its density lessened. Any fresh air which becomes admitted, at a lower temperature, finds its way along the lower portion or stratum of the confined atmosphere, and is only slowly heated and intermixed with the hotter and lighter air. Heated air, as stated, is lighter than air at a lower temperature, and it would ascend in the open atmosphere and share its caloric with the particles of air which it came in contact with, until it was reduced to the normal temperature of the surrounding atmosphere. In a close room it could not ascend, owing to the obstruction offered by the ceiling, and would naturally remain there, not, however, without admixture, to a certain extent, continually proceeding.

We have selected a close inhabited room, in order to describe these conditions, as it is nearer home to us than any other; but the conditions are not dissimilar to those which exist in the galleries of a coal mine, removed from the influence of air-currents, and the physical laws act in a manner precisely analogous.

Carbonic acid is given off by the breathing of men and horses, and by the combustion of oil or candles used to light a mine. The animal matters of breath are exhaled in like manner, and are condensed upon every cold and exposed surface. There is, unfortunately, a very serious addition to those enumerated, which is not met with in our dwellings, viz., the large volume of gases which is evolved from the seams of coal, &c. Moreover there is a much greater barrier existing 'twixt the outer atmosphere and the galleries of a coal mine than is the case with a room in a habitation. The unbearable state into which the atmosphere in a confined heading, drift, or level is thrown when it is extended some distance inwards, offered so great an obstacle to the successful working of coal, that the early miners were content, in many instances, with simply patching or getting coal in a manner similar to quarrying for stone. When, however, these surface stores became exhausted, through the vast extension of the iron industry and the demands of manufacturers, who began to experience the value of steam power, coal had to be sought at greater depths, and pits sunk, in order to reach beds of coal lying at considerable depths below the surface.

When a downcast shaft is being sunk, and some appreciable depth has been reached, the heated gases exhaled by the sinkers continue to rise upwards, because there is no top obstruction, but the atmosphere becomes more and more vitiated as they descend, owing to the inpour of gases with which the strata is impregnated; and the work is prosecuted with great difficulty. No such difficulty is experienced on the surface, though the atmosphere may have been calm and still for days together. The reason is obvious: mutual diffusion, aided by slight though imperceptible currents, goes on through a mass so large that its deterioration is small and unnoticeable; but a relatively insignificant portion, unmoved by outward tendencies, soon becomes so mixed with impurities as to be irrespirable. During the sinking of a shaft, the air in the same is to a certain extent moved by currents—as the heated gases rise upwards, a colder and heavier portion descends, and in this manner the pit air becomes removed and renovated.

When the bottom of the shaft is reached, and the work of constructing the galleries, &c. is commenced, there is so much difficulty experienced in obtaining a breathable atmosphere, that, without the aid of some artificial appliance, the work would soon have to be abandoned. The application of artificial power, in order to assist mutual diffusive force in mining operations, is termed 'ventilation.' The question as to the possibility of removing the gaseous matter which renders air unbreathable, and purifying it so that it can be again made serviceable, has been many times before the mining public; but it need scarcely be added that this is impracticable. If, in the crowded room or the heading of a coal mine, a quantity of lime-dust was scattered throughout the air, it would effect the removal of the carbonic acid, and thus get rid of one objectionable ingredient, but the 'cure would evidently be worse than the disease' in this case, because the action of the fine lime-dust in the air would be more unbearable for the lungs than the carbonic acid, and this project would have therefore to be abandoned. It has been said also that some compound might be brought in contact with the fire-damp evolved, and propositions of this kind have been made, but, until we know of a compound capable of absorbing it, and at the same time capable of being easily applied for the purpose, such futile ideas may well be disregarded.

For the safety and well-being of mankind, and in order to promote the development of nature's resources, and to ensure comfort in the dwellings of the millions, some universal agent is required to assist nature's laws when we alter, modify, or remove her regulations. At first sight this does not appear difficult, as the following illustrations show. A candle is burning in a still atmosphere, and when the hand is brought near to either side of the flame, very little heat is felt until it approaches almost directly against it. If, however, the hand is raised perpendicularly above the flame, the heat conveyed to the gases arising from the candle may be felt for a long distance upwards. This shows that the tendency of the heated air is to ascend, because of its lighter nature, and it rises at a rate proportional to the difference between the pressure of an atmosphere of the density of the heated gases and that of the surrounding atmosphere; so that if heat be applied in a room, and the heated products can escape at the top, and a supply of fresh air be admitted at the bottom, there will be a constant circulation and admixture of the gaseous contents, which are continually ascending upwards and which are displaced from below by a fresh supply.

Let a small blast of air be directed against the side of the candle; if the hand be held near to either side, at right angles to the current of air, more heat will be felt at a greater distance than in the previous experiment with the candle in a still atmosphere; and if the hand be placed at the side of the candle, directly in front of the current of air playing upon it, a degree of heat equal to that felt directly above the flame in the previous experiment will be experienced, while, in the present instance, the heat is very sensibly lessened in that position.

Heated gases, then, rise upwards with a force equivalent to their lessened density, and if a superior force is brought to bear on them they will become subservient to that force, but as soon as they are removed from its influence, or the force has become expended, the heated gases will ascend again until deprived of their heat by the surrounding particles of air. If, instead of admitting a current of air directly against the candle in an apartment, air is propelled into the latter at a distance underneath, the heated gases will rise more rapidly, and directly in ratio to the force of the current generated. By the employment of such forces, that is to say, heated air or forced currents at the ordinary temperature, in a room, having means of exit afforded near the ceiling, the atmosphere would be in continual motion, and any products generated by breathing, or other cause, would be removed, the rate of removal depending upon the travelling rate of the current produced by the power employed.

This is the condition of the atmosphere during the prevalence of wind, and, to a certain extent, during the most calm weather. Heat is conveyed from the earth by convection to the particles of air immediately above it, and these heated particles ascend and are continually displaced by colder air. At the equator, the temperature of the atmosphere is materially higher than toward the poles, or than it is in the temperate regions. Owing to the unequal distribution of heat over the earth's surface, the cold air has a tendency to move in the direction of the hotter air, which ascends upwards at the equator by the intense heat causing rarefaction and lessened density, and this is, in fact, what takes place. Currents of air are always circulating from either pole towards the equator, and were it not for the axial motion of the earth, these currents would furnish winds blowing in a north and south direction. The trade winds, monsoons, &c., are produced in this way.

As there will be occasion again to refer to the force and power of wind, it will be as well to consider here what that force or power amounts to. In this country and, in fact, in the northern hemisphere generally, S.W. or N.E. winds prevail. In addition to this exciting cause, there are land breezes due to the unequal heating of land and water, by the influence of the sun's rays. An oppositely working cause, also, determines the motion of air-currents by night, owing to the condensation of moisture and to the radiation of heat from the earth's surface.

These causes are naturally at work in our own island, and on this account it is that the atmosphere is maintained in a salubrious condition and in a state of uniform admixture.

TABLE OF THE VELOCITY AND FORCE OF WIND.

Velocity of the Wind		Perpendicular Force on One Square Foot in Avoirdupois Pounds and Parts	
Miles per Hour	Feet per Second		
1	1·47	·005	Hardly perceptible
2	2·93	·020	Just perceptible
3	4·4	·044	
4	5·87	·079	Gently pleasant
5	7·33	·123	
10	14·67	·492	Pleasant, brisk
15	22·00	1·107	
20	29·34	1·968	Very brisk
25	36·67	3·075	
30	44·01	4·429	High wind
35	51·34	6·027	
40	58·68	7·873	Very high wind
45	66·01	9·963	
50	73·35	12·300	Storm or tempest
60	88·02	17·715	Great storm
80	117·36	31·490	Hurricane
100	146·7	49·200	Hurricane that tears up trees and carries buildings before it

Some of the general laws connected with the artificial appliances used to give rise to ventilation currents, and the effect of atmospheric influences, will be next considered. The pressure of the atmosphere is equal in every direction, and is represented by a column of mercury averaging 30 inches in height, which is equal to a pressure of 14·7 lbs. upon the square inch. The standard of barometric height and pressure is taken at sea level. If one ascends a mountain and takes up a barometer, it is found that the column of mercury lowers, and this lowering takes place gradually and regularly, and it has been determined, from experiment, that for every 900 feet ascended, the mercury in the barometer tube lowers one inch; so that if the barometer registered 30 inches at sea level when one began to ascend the mountain, and remained stationary at 30 inches at sea level, during the experiment, when a height of about 4,500 feet had been reached, the mercury in the barometer would stand at only 25 inches instead of 30 inches.

Now the mouth or top of some coal-mine shafts, in fact the majority of them, are at a very appreciable height above sea level, and even the bottom of many mines are considerably above sea level, so that barometric readings recorded at the various observatories —and they are always recorded after correction to sea level—will not coincide, in the majority of instances, with the readings taken either at the top or bottom of mine-shafts. It is not at all improbable that the galleries or headings in several mines are on a level, or nearly so, with that of the sea, and, if it be so, the sea-level reading will be the reading of the barometer in such mines, provided the atmosphere is of equal height at both places. It follows, therefore, that if a barometer be taken down the shaft of a mine, and a descent of 900 feet has been made, it will register 1 inch higher than it did at the surface, and so on according to the depth descended. The same observations may be noticed in descending any neighbouring pit, whose surface stands at the same level above the sea, so that at all equal depths within the range of equi-barometric indication, the barometer readings will be equal, and as a matter of fact the pressure will be equal. If the mercury in a barometer stands at 31 inches in the bottom of a shaft, and the same barometer indicates 30 inches at sea level, the pressure of the atmosphere at the bottom of the shaft will be more than 14·7 lbs. to the square inch, in fact it will be 1-30th more, or nearly 15·2 lbs. per square inch. For every inch of rise in the mercurial column of the barometer the pressure will increase ·49 of a lb. per square inch, or for every fall of 1 inch, the pressure will decrease ·49 of a lb. per square inch of surface, irrespective of the actual height of the barometer.

The temperature of the earth at or near the surface will depend, almost entirely, upon the local temperature of the atmosphere, and will differ, naturally, according to the season of the year; it will be much lower in winter than summer. When some depth below the surface of the earth is reached, as, for instance, in sinking the shaft of a coal mine, the local influence of season upon temperature at the surface, ceases to be felt, and a rise of temperature, above the local mean of the neighbourhood, is experienced when greater depth is attained. At a depth of several thousand feet below the earth's crust, it is computed that the temperature approaches that of a red heat, or, as it is sometimes termed, 'of fire.' There is no clear evidence to prove that the temperature of the earth (internally), is the same at all places at equal depths above or below sea-level, and, consequently, no tabulated statement of the temperature at varying depths below the earth's surface can be given. It has been ascertained that for about every 60 feet in depth, the temperature rises 1° on Fahrenheit's scale, after the line of mean equal annual temperature has been passed, but this appears to be a somewhat high estimate.

We have every proof, however, that the temperature does rise with the depth, and, as gases expand and become lighter when heated, some correction must be made for any rise of temperature which may be experienced at the bottom of a mine above that at the surface, when calculating the various data connected with ventilation. The temperature of the galleries or headings in a mine will depend, in no slight measure, upon the quantity of air which passes through them, as well as upon the depth from the surface. If the mean temperature of a series of galleries be 65° F., and a current of air passes through them whose temperature is only 40° F., that current will become heated (but very gradually, as gases are not good conductors of heat) until it approaches the temperature of the mine. The temperature of a mine is also considerably influenced by the heat generated and evolved from the lungs and skin of animals, and the burning of oil, and it very frequently happens, that at the end of the workings, the temperature is much raised, owing to the circumstances alluded to, until it often reaches 80° F., and even higher. This is especially the case with headings into virgin ground, and other working portions not in direct communication with the air courses, and where the amount of air travelling is limited and deficient. Such a temperature should be avoided, however, in all cases when practicable, and it should not be allowed to rise above 70° F. (mean), because any atmosphere of this kind cannot be healthy, holding, as it must do, the gases and organic matters evolved from animal sources, in addition to the gas given off by the coal.

As stated, air admitted into the galleries of a mine, from the surface, at a lower temperature than that of the mine itself, expands as it becomes elevated in temperature, but cannot escape upward by virtue of its lessened density, owing to the 'top' obstruction, and it was early found that no current of air could be successfully drawn or driven through a mine, unless two communications were afforded with the surface, an inlet and an outlet or an upcast and a downcast shaft. Two shafts are sunk which communicate with each other, though, in practice, not directly, in order that, by a circuitous route, air may be drawn through all the workings before finally leaving by the upcast shaft. If the heated air referred to were led to ascend either shaft by temporarily heating the galleries in the direction of that shaft, or better by applying heat in the shaft itself, a self-acting current would pass uninterruptedly from one shaft to the other, and so introduce fresh air into the workings. If the mine were a deep one, where the temexpanded 1 foot for every degree of difference between 0° and 32°, and will become

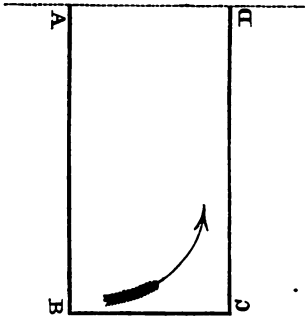
$$459 + 32 = 491 \text{ cubic feet.}$$

For example, it is required to know what volume 100 cubic feet of air, measured at 50° F., will occupy at 60° F.:—We have first to find the expansion of 459 cubic feet from 0° to 50° F., the temperature at which the 100 cubic feet were measured, which will be $459 + 50 = 509$. Now to find the volume 459 cubic feet will occupy at 60° F., as before, we have 519, and by dividing 519 by 509, and multiplying the product by 100, we have

$$\frac{519 \times 100}{509} = 101{\cdot}96,$$

which shows that 100 volumes of air expand 1·96 volumes, or 100 cubic feet expand 1·96 cubic feet, by becoming heated from 50° to 60° F.

In order to facilitate the calculation of the difference in weight due to the lessened density of air in the upcast shaft, the tables on page 282 have been compiled by the author, and from these the weight of any column of air, in either shaft, can be determined, and, as an example, an instance of the power obtained by natural ventilation will be taken. Let A B, C D represent two shafts, and B C the communication between them, in the bottom of the mine, and natural ventilation is proceeding in the direction of the arrow. The barometer registers $29\frac{1}{2}$ inches at the top and $30\frac{1}{2}$ inches at the bottom of the downcast shaft, A B, and the temperature of the air is 40° F., and the temperature of the return air in the upcast shaft is 70° F. The two shafts are of equal depth, viz. 900 feet. The average height of the barometer would be 30 inches. From the table on next page, 100 cubic feet of air at 40° F. weigh 7·945 lbs., and the pit being 900 feet deep, which represents 900 cubic feet of air column, therefore



$$7{\cdot}945 \times 9 = 71{\cdot}505 \text{ lbs.},$$

or, in other words, the pressure on every square foot due to the weight of the column of air at a temperature of 40° F., and 900 feet high, is 71·505 lbs. 100 cubic feet of air at 70° F., under a barometric pressure of 30 inches, weigh 7·497 lbs., which, multiplied by 9, gives 67·473 lbs. as the weight of 900 cubic feet of air column at 70° F., then

$$71{\cdot}505 - 67{\cdot}473 = 4{\cdot}032 \text{ lbs.},$$

which is the difference in weight between the air-column in the downcast and upcast shafts.

In the open air, a pressure of 4 lbs. to the square foot gives rise to a wind travelling at the rate of expanded 1 foot for every degree of difference between 0° and 32°, and will become

$$459 + 32 = 491 \text{ cubic feet.}$$

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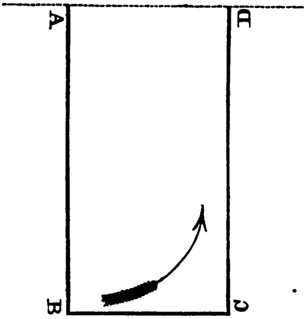

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which is the difference in weight between the air-column in the downcast and upcast shafts.

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Weight of 100 *Cubic Feet of Air in lbs. at different Temperatures and under different Barometrical Pressures, and Increase in Volume of* 100 *Cubic Feet of Air by* 10 *degrees of Heat above* 32° *F.* (0° *C.*)

Temperature on Fahrenheit's scale	Weight of 100 cubic feet of air in lbs., bar. 29 in.	Difference between 10 degrees in temperature in parts of a lb.	Weight of 100 cubic feet of air in lbs., bar. 30 in.	Difference between 10 degrees in temperature in parts of a lb.	Weight of 100 cubic feet of air in lbs., bar. 31 in.	Difference between 10 degrees in temperature in parts of a lb.	Difference in weight of 100 cubic feet of air due to a rise or fall in the barometer of 1 inch	Expansion of 100 cubic feet of air by being elevated in temperature 10° F.
30	7·838	—	8·108	—	8·378	—	0·270	—
32	7·805	—	8·074	—	8·343	—	0·269	100·00
42	7·680	0·158	7·945	0·163	8·210	0·168	0·265	102·04
52	7·530	0·150	7·790	0·155	8·050	0·160	0·259	104·07
62	7·387	0·143	7·641	0·149	7·895	0·155	0·254	106·11
72	7·247	0·137	7·497	0·144	7·747	0·148	0·250	108·14
82	7·113	0·134	7·358	0·139	7·603	0·144	0·245	110·18
92	6·984	0·129	7·225	0·133	7·466	0·137	0·241	112·22
102	6·861	0·123	7·097	0·128	7·333	0·133	0·236	114·25
112	6·740	0·121	6·972	0·125	7·204	0·129	0·232	116·29
122	6·624	0·116	6·852	0·120	7·080	0·124	0·228	118·32
132	6·512	0·112	6·736	0·116	6·960	0·120	0·224	120·36
142	6·403	0·109	6·624	0·112	6·845	0·115	0·221	122·39
152	6·299	0·104	6·516	0·108	6·733	0·112	0·217	124·43
162	6·198	0·101	6·411	0·105	6·624	0·109	0·213	126·47
172	6·099	0·099	6·309	0·102	6·519	0·105	0·210	128·50
182	6·003	0·096	6·210	0·099	6·417	0·102	0·207	130·54
192	5·910	0·093	6·114	0·096	6·318	0·099	0·204	132·58
202	5·820	0·090	6·023	0·093	6·223	0·095	0·201	134·62
212	5·735	0·087	5·933	0·090	6·131	0·093	0·198	136·66
222	5·651	0·084	5·846	0·087	6·041	0·090	0·195	138·69
232	5·569	0·082	5·761	0·085	5·953	0·088	0·192	140·73
242	5·490	0·079	5·679	0·082	5·868	0·085	0·189	142·76
252	5·413	0·077	5·600	0·079	5·786	0·082	0·186	144·80
262	5·338	0·075	5·522	0·078	5·706	0·080	0·184	146·84
272	5·265	0·073	5·446	0·076	5·627	0·079	0·181	148·88
282	5·193	0·072	5·372	0·074	5·551	0·076	0·179	150·92
292	5·124	0·069	5·300	0·072	5·477	0·074	0·176	152·96
302	5·057	0·067	5·231	0·069	5·405	0·071	0·174	155·00

28 miles per hour, and this velocity is vastly greater than th in the upcast shaft of any mine. T rvation, it appears that the

average velocity of the air in the upcast shafts of coal mines is about 20 miles per hour, which is equal to a pressure of 1·968 lbs. per square foot in the open air. Apparently, therefore, it is a matter of no difficulty, in the face of the variations of temperature on the surface, to ventilate a colliery, as by maintaining the temperature of the air in the upcast shaft some 20° or 30° F. above that in the downcast, the air-currents could be set in ample motion, and an unlimited quantity of air employed to sweep out the gases evolved and generated in the workings; but in the open air little resistance is encountered, and the pressure giving rise to a wind travelling at the rate of 20 miles per hour bears no comparison whatever to the force required to give rise to such a velocity in the ventilating current of a mine. Air has weight and density, and gases, like liquids and solids, press and rub in the act of moving, and give rise to friction. It is, therefore, the resistance which air meets with in travelling through the narrow galleries of a mine, which interferes with its velocity, and the pressure required to produce a velocity in the air-current travelling at the rate of 20 miles per hour will depend upon the amount of resistance which it meets with; or, in other words, the actual area of the surface exposed, together with the impediments which it encounters in its course.

In practice, when artificial ventilation is produced by furnace action, the temperature of the air in the upcast shaft is maintained at 200° F. or more. An example or two, illustrative of the total pressure derived from heat applied to produce artificial ventilation will be given, in order to render calculations from the table more easy. The total pressure includes, obviously, that due to 'natural' as well as applied ventilation.

Let us suppose that the depth of a downcast shaft is 460 feet, and that of the upcast shaft 533 feet, and that the bottom of the two shafts is level. It is necessary to take the height of the barometer, and the average temperature in the downcast; but, in this instance, there is a difference of 73 feet between the depth of the two shafts. Now the pressure of the atmosphere being the same in all directions, its actual pressure upon the mouth of the downcast will be practically identical with that which would be experienced at *that point*, if the downcast shaft were walled up to the level of the upcast, *i.e.*, for 73 feet, so that by adding the 73 feet to the depth of the downcast and halving it, or, in other words, by halving the depth of the upcast, which would be 266½ feet, and taking the height of the barometer at that distance from the bottom of the downcast (or at 193½ feet from the top of the downcast) the average height of the barometer would be obtained. Were it required to be known how much loss there was in working or available pressure due to friction in the downcast shaft, it follows naturally that the calculation would have to embrace only the actual rubbing surface (460 feet deep). The temperature of the 73 feet of air above the pit will have to be taken into consideration, but this will not vary to any perceptible extent with that on the surface, unless there is much local influence. It may be remarked also that the relative diameter of either pit makes no difference whatever upon the total pressure of the atmosphere, so far as considerations regarding ventilation are concerned. The diameter of a downcast shaft may be 20 feet and that of the upcast only 10 feet, or *vice versâ*; the relative pressure of the atmosphere would be the same upon each square inch or foot of surface. In calculating the weight of air-column in either shaft, it is not the total number of cubic feet, or the total cubic contents that is required, but simply the weight of a column of air which measures 1 cubic foot for every foot in depth; and if the difference in the weight of a column of air in a downcast shaft above that in the upcast was equal to a pressure of 18 lbs. to the square foot, and the diameter of the downcast was 16 feet, no increase of pressure would be obtained by making the downcast shaft 20 feet in diameter, nor would the pressure be reduced if the diameter of the downcast were reduced.

The total amount of ventilating power obtained by increasing the temperature of the air in the upcast shaft depends entirely upon the depth of the shafts, and not in any degree upon their areas; these remarks have, however, no bearing on 'friction.'

The temperature of the atmosphere varies according to the season of the year—in winter it may be some degrees below freezing point, and in summer it may rise to 80° F. This difference of temperature is very considerable, and exercises a continual influence upon the ventilation of a mine, no matter by what agency it is brought about. For example, the ventilating pressure in a mine 1,000 feet deep will be taken—the temperature on the average in the downcast shaft is 40° F. and in the upcast 200° F., and the barometer stands at 30 inches midway, the depth of the downcast and upcast being equal. The temperature of the air in the downcast is sometimes lower than 40° F., but it is not usually allowed to fall much below this, as it endangers the walls of the pit, which would be liable to burst in if the water became frozen, and, on this account, fires are kept burning at the mouth of the downcast in frosty weather.

1000 cubic feet of air at 40° F. weigh 7·945 × 10 = 79·45 lbs.
" " " " 200° F. " 6·023 × 10 = 60·23 "
Difference in weight of air-columns . 19·22 "

Now if the temperature of the downcast were raised from 40° F. to 80° F., what would be the result?

1000 cubic feet of air at 80° F. weigh 7·358 × 10 = 73·58 lbs.
" " " " 200° F. " 6·023 × 10 = 60·23 "
Difference in weight of air-columns . 13·35 "

There is, therefore, a difference of nearly 6 lbs. per square foot, or nearly 30 per cent. of the total pressure lost, owing to such a rise of temperature. From the above figures it will be seen that a sudden fall or a sudden rise in temperature may be the means of causing a great decrease or increase in the ventilating pressure, or, rather, weight of the column of air in the downcast shaft, and the ventilating current must be seriously affected by it. Unless there is some means provided whereby the influence of a rise in temperature equal to 40° F. can be overcome, there will be a loss of pressure equal to nearly one-third of the total, in a deep mine, under the conditions above referred to. In other words, if 100,000 cubic feet of air per minute were circulating, when the temp[illegible]ure of the air was at 40° F. in the downcast, there would be a reduction equal to about 20,000 cubic feet, if the temperature of the air in the downcast were raised to 80° F.; the decrease of velocity, however, would reduce the friction very considerably.

Now it is not assumed, for a moment, that in the ordinary course of mine-working, variations of temperature equal to 40° F. are experienced, either at regular or irregular intervals, but we are well acquainted with the fact that the temperature falls in winter often below 32° F. and in summer it reaches above 70° F., showing that there is a range of 40° F. between summer heat and winter cold.

It will be well to define, once for all, what the effect of temperature upon mine-ventilation amounts to in practice, because the results of an increase of temperature are supposed by many to be counteracted by other means. It is not the artificial power applied which suffers much, nor would temperature affect mine-ventilation to a very sensible extent, provided the mean temperature of the return air-currents at different seasons of the year were the same as that of the air in the downcast shaft. The difference between the mean temperature of the galleries of a mine during the summer and winter months is seldom more than from 5° to 10° F., while the difference on the surface, as we have seen, is more than 40° F. If the galleries of a coal-mine are level, or nearly so, then the return air as it enters the furnace will only differ in temperature from 5° to 10° F. throughout the year, and the temperature of the upcast will be higher when a hotter current enters the furnace than when a colder one does.

But it is evident that—when, as before, the galleries are about level—whatever difference exists between the mean temperature of the air in a mine during the year and the lowest temperature at which air is allowed to enter the downcast, will be the measure of the total loss of ventilation-power brought about by the effect of temperature. For instance, say the lowest temperature of the air as it enters the downcast in winter is 35° F., and the mean temperature of the return air-courses during the year is 65° F., then the effect of temperature upon ventilation could be measured by calculating the difference in density caused by 30° F. of the air-column in the upcast and downcast shafts. It really amounts to this, that could we regard *natural* ventilation apart from *artificial* ventilation, the benefit of the former is *nil* during hot summer weather, and a very considerable acquisition during the winter months, and this loss or gain of ventilation from the natural heat of a mine is in no way compensated for by the furnace, provided the same quantity of coal is always used.

If the coal is worked to the dip, and at an appreciable angle, the effect of natural ventilation is very complicated, and in many instances there will be little benefit therefrom at any season of the year, owing to the tendency of the heated gases to ascend against the down-current.

As an illustration of the influence which the depth of the mine exercises upon the amount of ventilation obtaine[illegible]e action, the following example [illegible]be taken that a pair of sha[illegible]hat the temperature and barometric readings are the same as those before given in the case of the shafts 1,000 feet deep, what would be the difference in the ventilation-power, calculating as before, that it is proportional to the difference in weight between the two air-columns ?

500 cubic feet of air at 40° F. weigh 7.945 × 5 = 39·725 lbs.
„ „ „ „ 200° „ „ 6·023 × 5 = 30·115 „

Difference in weight of two air columns . 9.610 „

Now, this is exactly one-half of the available pressure in the case of the pit 1,000 feet deep; and, as it is only one-half of the depth of the latter, it follows that, if the temperature and other conditions are alike, the amount of ventilating power obtainable by furnace action will be in ratio to the depth. In practice, however, it usually happens that the mean temperature of the upcast in shallow mines is somewhat above that of the mean in deep mines, which makes a little difference and adds to the ventilating power.

There is, nevertheless, a very great difference between the power obtainable in deep and shallow mines; and the advantage of the former over the latter, when both employ furnace action, must be obvious on comparing the examples given, which are really the results found in practice. A good high stack above the upcast in shallow mines is very commendable. This is, however, impracticable when the upcast is used for raising coal; but raising coal by the upcast is a dangerous operation, and should not be carried on in shallow mines, especially those in which furnace action is employed. There is much power expended and lost by the continual raising and lowering of the trams in the cages, which absorb no small amount of heat from the ascending gases, and also tend to form a downward current, so that a column of cold air shall descend on either side of the shaft alternately with the raising and lowering of the cages.

In the autumn, winter, spring, and, indeed, frequently during the summer, the temperature of the air differs considerably, being higher in the day than in the night. In December, January, February, and March, weather is often experienced during which there is a sharp frost at night, with a bright sun in the day—one day the thermometer may rise to 50° F., and at night be as low as 30° F., and on the following day 40° F., and continue to rise and fall irregularly. A difference of 20° F. will affect the ventilating current in a very appreciable measure, much more, in fact, than is generally credited—and on comparing the effect side by side with the considerations respecting the variations due to barometric pressure, it will become evident that, although the latter has usually to bear the ill name of being the miner's dread, the temperature should occupy his attention in an equal degree. As before observed, the pressure of the atmosphere when the barometer stands at 30 in. is equal to 14·7 lbs. to the square inch, or 2,118 lbs. to the square foot, and a difference of one inch of fall in the mercurial column will reduce that pressure by ·49 of a lb. per square inch, or 70·6 lbs. per square foot. It is rarely, indeed, that the barometer falls through 1 inch suddenly, but a rapid fall of ½ inch is [illegible] urrence; and by way of ex [illegible] its effects by the side of that due to temperature, and take as an instance the pit 1,000 feet deep already referred to, where the total difference in weight between the two air-columns amounted to 19·22 lbs. when the barometer stood at 30 in. If the barometer fell ½ inch, or, in other words, registered 29½ in., the difference in weight of the two air-columns would be

1,000 cubic feet of air at 40° F., bar. 29½ in. = 78·13 lbs.
" " " " " 200° " " " " = 59·23 "
18·90 "

19·22 − 18·90 = 0·32 of a lb.

The effect of a reduction of barometric pressure equal to half an inch would be, therefore, a loss of ·32 of a lb. of working or available ventilating power. The consequences incidental to an appreciable increase in the temperature of the air entering the downcast shaft would, obviously, be more serious than this.

The effect of decreased atmospheric pressure is, however, one which exercises a very great influence upon the working of a colliery, as its results are felt in more ways than one. Where the means of generating, so to speak, the power of ventilation are limited, and not above that required to maintain the galleries in a salubrious condition, it follows that a lowering of ventilating pressure, small though it may be, would naturally make itself felt. More than this, the barometer may continue to fall, the variation during the space of one week reaching probably 1½ inches. For instance, during fine weather the barometer may have risen to 30½ inches, and in a succeeding week of rain and stormy weather it may fall to 29 inches; in fact, the variation oftentimes reaches greater limits than this. The barometer varies in height in our island, at sea level, from 29 to 31 inches—rarely exceeding 31 inches in height, and equally as rarely falling below 29 inches. This total difference of 2 inches would affect the ventilating pressure in the pit 1,000 feet deep thus:—

1,000 cubic feet of air at 40° F., and bar. 29 in. = 76·80 lbs.
„ „ „ „ 200° „ „ „ „ = 58·20 „
18·60 „
1,000 cubic feet of air at 40° F., and bar. 31 in. = 82·10 „
„ „ „ „ 200° „ „ „ „ = 62·23 „
19·87 „

The total effect of barometric fluctuation upon the difference in weight of the two air-columns would be 1·27 lbs. per square foot.

There are, as mentioned, other disastrous influences exercised by barometric depression; these are, principally, inpour of gas in increased quantity, and falls of material through the lessened resistance offered by the atmosphere, and the expansion of gaseous mixtures which may have been pent up in goaves or cavities, in which the mixture of gas and air exist at the prevailing pressure of the atmosphere in the mine. If the fire-damp evolved from the working face of coal, from fissures in the rock, and from all communications whatsoever in connection with supplies, gained access into the workings under a pressure like that of the atmosphere, and made its way simply by diff [illegible] it would be, perhaps, possible to [illegible] atio of the amount of gas w [illegible] mine under different barometric pressures; or if it were possible to arrive at the actual volume of gas which escaped into the workings when the barometer registered 30 inches, or, in fact any known pressure, it would be simply a matter of calculation to find the effect—so far as an increased quantity of gas is evolved—of a decreased pressure, equal to one inch or more of mercury. This is, however, utterly impossible. The working face of coal contains gas under immense pressure, which is forced outwards by the greater pressure of the gas in the coal immediately behind it, while the coal still further back contains gas under greater and greater pressure.

The area of all cavities, goaves, and other receptacles in which fire-damp may be stored up can be found, and the law of gaseous expansion will teach us to what extent an inpour of gas may result from these sources through barometric depression. *The volume of a gas varies inversely as the pressure upon it.* A reduction of barometric column of 1 inch—1-30th of the pressure—would cause a gas to expand 1-30th of its volume, and the mixtures of air and fire-damp in the goaves, &c., would expand 1-30th through a fall of 1 inch in the barometric column; or, in other words, 1-30th of the total quantity of gas so stored up would be forced into the workings of a colliery by the lowering of the barometer 1 inch.

Although the goaves and other receptacles, where they exist, form dangerous reservoirs of explosive gas, it is the generating supply which replenishes these, as well as continually pours enormous volumes of fire-damp into the workings of a mine, which chiefly claims attention. A seam or vein of coal is practically an immense reservoir of gas, or gasometer which contains it, not under atmospheric pressure, or in quantity equal to its own mass, but in many instances in incredible quantity, the actual volume being dependent upon, or subject to, a host of conditions, such as the nature of the coal, its geological age, the thickness of the seam or vein, the structure of the coal, the porosity or hardness of the same, the depth of the seam from the surface, the nature of the rock or other material which lies above, the position in which it lies in the coalfield, the number of collieries in the district, the disturbances to which the strata may have been subjected, the proximity to the neighbourhood of faults, the length of time which any neighbouring portion may have been worked, the length of time which the colliery itself has been in operation, the number of seams of coal worked, whether any seams of coal above or below are unworked, and numerous other considerations.

In some mines situated at a great depth from the surface, and in the centre of a large basin, much of which remains unworked, the pressure under which the enclosed gases or fire-damp is pent up must be incredibly great. Were it possible to arrive at something like a correct estimation of this pressure the results would be extremely interesting; but, unfortunately, it is too probable that this end will never be attained. The author has estimated the quantity of enclosed gas in some samples of steam coal from the South Wales basin which had not been removed many hours from the mine, and found that they contained gas equal to nearly 20 times their volume. Without taking into consideration the mass of the coal, 20 volumes would represent a pressure of nearly 300 lbs. to the square inch, if the gases were held simply by the strength of the pores or interstices of the coal in which they were imprisoned. Before these samples were won from the seam—in fact, when they formed part of the mass of unworked coal—what must have been the pressure under which the gas was confined? Would 100 atmospheres cover that pressure? It is not probable that they would. We will not attempt further to solve this unfathomable problem in reference to the effect of decreased pressure upon the actual quantity of fire-damp evolved.

The lessened resistance caused by a barometric depression of 1 inch does not, at first sight, appear to be very considerable; it represents, however, 70·6 lbs. to the square foot; and this pressure, extended over 12,000 or 15,000 square feet of coal, would, cumulatively, mean a much-increased inpour of fire-damp.

Mr. Joseph assumes [1] 'that in the normal state of coal (South Wales coal-field), previous to the appearance of the slip cleavage, the bituminous matter held chemically in every ton of coal was equal to a volume of 10,000 to 12,000 cubic feet of coal-gas of initial weight and density. When the slip cleavage made its appearance in the coal seams the bituminous matter became decomposed or volatilised into fire-damp, the consequence being that in the fiery zone all the lower series of coals, from the 2 feet 9 inches to the lower 4 feet, will be found to contain bituminous matter equal to about 7,000 cubic feet of coal-gas in every ton of coal, and 4,000 to 5,000 cubic feet of fire-damp. The less bituminous steam-coals will not produce more than 5,000 cubic feet of coal-gas, leaving from 6,000 to 7,000 cubic feet of fire-damp lodged in the coal and intervening strata.' Mr. Joseph further states that the mean of the two estimates indicates that every ton of coal, with its contiguous shales, holds mechanically 5,000 cubic feet of fire-damp; being compressed in the coal itself about two hundredfold, or into 200 times its initial weight and density. Mr. Joseph adds: 'Is it strange, then, when we bear in mind that each 5,000 cubic feet of fire-damp is equal to form an explosive compound when mixed with 14 times its own volume of atmospheric air, that the sudden irruption of a blower of gas may in a few minutes place the *best-regulated isolated colliery* working the coal to the rise in a state of extreme danger?'

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[1] Proc. South Wales Institute of Engineers, May 1871.

Mr. Joseph estimates that there are 50 feet (in numerous veins) of steam-coal, in the lower series, which, with the contiguous strata, contain a quantity of fire-damp amounting to 80,000 cubic feet per superficial yard, capable of forming an explosive mixture equal to 1,120,000 cubic feet.

The method of calculation, dating from the amount of bituminous matter which was present in coal previous to the slip cleavage, is as novel as it is ingenious. How much of the bituminous matter may have been converted into carbonic acid and water is a question which cannot be decided. Mr. Joseph does not premise that the figures above given are more than assumed, although he appears sanguine of offering exact figures if a series of experiments were made with the various coals in gas retorts.

e above figures will convey a good idea of the
ormous quantity of gas present in steam-coal, but
ere is no material whereby to calculate the quantity
gas present in the enclosed form in coal, although
e figures assumed by Mr. Joseph are not probably
errated. A two-hundredfold compression means
at the gas is pent up in the coal, &c., under a pres-
re of 2,940 lbs. to the square inch. It will be readily
derstood, therefore, that under barometric varia-
ns much diligence and watchfulness are necessary
order to prevent an explosion, and that, too, a
onger current of air is wanting, so as to sweep out
e extra quantity of fire-damp evolved.

CHAPTER XII.

VENTILATION CONTINUED—APPLIANCES USED TO GENERATE VENTILATION—FRICTION OF AIR IN MINES.

HAVING noticed the effect of atmospheric influence upon ventilation, the appliances used to generate the ventilating current will be next considered. They may be divided into two classes—direct application of power as furnace heat, and mechanical appliances.

In the first class the furnace stands alone. Furnace ventilation is the most simple and direct application of ventilation-power which it is possible to obtain. All ventilating power, by whatever means afforded, depends upon rarefaction, and the simple application of heat to the column of air in the upcast shaft implies the expansion of the particles of air, and, consequently, rarefaction. Furnace ventilation depends upon the amount of heat which can be conveyed to, or the rise of temperature incidental upon the gases of the ventilating current being used to support the combustion of coal.

For this purpose a large fire-bed, from 8 to 10 feet wide, is placed either on a level with the seam of coal or at some distance above or below, according to circumstances. Coal is placed on this fire-bed, and, as soon as the fire is kindled, the air which supports its combustion becomes heated and rarefied, and rushes upwards, while a further quantity supplies its place, and in turn is subjected to the same conditions. After a time the heated gases in the upcast shaft part with their caloric to the walls of the shaft, until, to a certain extent, they are equally heated. When this end has been attained, and the furnace is in full work, the ventilating power will be felt throughout the workings, a column of fresh and heavier air descending the downcast shaft, while the return air and heated gases ascend the upcast shaft.

Theoretically and practically, of course, the amount of ventilation obtainable from furnace action will depend upon the difference in weight of the two air columns. On this account it is said that the heavier current of air in the downcast shaft forces upwards the lighter column in the upcast shaft, and through the continuity of these circumstances fresh air is admitted into the workings, so as to maintain them in a salubrious condition, and to sweep out the mine gases as fast as they are evolved. At the same time, however, the improper consideration of the subject has led some of the enemies of furnace ventilation to state that there is a material difference between the action of furnace and fan ventilation, the former being likened to propulsion, and the latter to traction.

Although furnace ventilation depends upon the greater weight of the air column in the downcast shaft, it does not follow that the ventilation would be propelled. The motive power is that exercised by the heat in driving asunder the particles of air, which by virtue of their lessened density have a tendency to rush upwards as the pressure of the atmosphere is exerted in an equal degree upon the mouth of either shaft, provided they are in the same level. If, correctly speaking, the air-current were propelled, the power expended should be applied in forcing the air down one of the shafts, the ventilating power depending, not upon the heat generated in the other shaft, but upon the amount of pressure applied in excess of that of the atmosphere.

Ventilation currents which are generated by the means at present in use are, correctly speaking, *induced* currents, and not *propelled* currents. In spite of the numerous inventions for producing ventilating power the furnace has not fallen into disuse, nor is it likely to. Its simplicity and easy adoption and continuity of action will ever continue to give it the preference in deep mines when proper attention has been paid to the laying out of airways of ample area. The effect of temperature upon ventilation which is dependent upon heat is naturally greater than on that which is derived by mechanical means (acting by displacement), and in shallow mines the difference in weight of the two air columns, dependent as they are upon the depth, is not sufficient to leave a margin broad enough to cover all contingencies.

Furnace ventilation, too, when it is used in shallow mines (and not unfrequently in deep ones), has to contend with much water, which continually cools the sides of the shaft, and, in consequence, much of the heat is lost in converting the water into steam. The cooling effect of water on the heated current in the upcast is much more considerable than is generally believed.

Some authorities, prejudiced in favour of fan ventilation, have asserted that one of the great advantages of the fan, or mechanical appliance, over the furnace is in case of an explosion taking place. It is urged that the ventilating current would be but momentarily impeded, and the foul gases incidental to the ignition of the fire-damp would be speedily brought off, and so be the means of saving those who were not the victims of the fire and violence of the explosion. Such an end is very desirable, as it is generally known that more lives are lost through the after-damp than through the fire and violence of the explosion. The arrangements for dispersing and regulating the ventilating currents are not, however, different in principle, whatever power is employed. The necessity of splitting the air, so as to decrease its velocity, has been generally admitted, and the means whereby this end is attained would be similar whether fan or furnace action is used. When the ignition of an explosive mixture has taken place it does not step to inquire about the power brought to play in generating air-currents, as the same doors, brattices, conveyances, regulators, &c., would be placed in either case dependent, of course, upon the arrangement of the workings; and the damage caused to the doors, regulators, &c., by the explosive force would be similar, so that a great portion of the workings of a colliery may be completely and effectively isolated, and, in spite of the most energetic action of mechanical power, little air would circulate in the isolated portion. Moreover, by the time that the destruction caused by an explosion had been partially remedied the furnace, even if extinguished, could in the majority of instances be got into working order, admitting sufficient air from the downshaft to neutralise, if necessary, the fire-killing effects of the carbonic acid and nitrogen. Again, if a portion of the coal took fire—as, unfortunately, it often does—the fan would be of no extra benefit, as it is imperative in such instances to keep down the ventilating current. Lastly, let it be assumed that the doors and regulators had been temporarily set right, and it had been ascertained, with almost certainty, that no coal was on fire, and, in consequence, it was decided to induce as much air as possible through the workings, then the full power of mechanical means would be of enhanced service; but should any accident happen to the fan, or engine driving it, so as to render it unworkable, the position of affairs would be lamentably unfortunate. It may be argued that it is absurd to calculate upon an accident occurring to the fan or engine driving it just at the period mentioned, but fate rules that misfortunes are cumulative, and do not come singly, and the mere fact of increasing the velocity by a few extra revolutions per minute may determine a break-down. Owing to the liability of mechanical ventilation-appliances to accidents the furnace is to be preferred in deep mines; in shallow mines, however, the former are more powerful, and consequently more desirable.

The mechanical appliances which have been invented for ventilation purposes are too numerous to mention, and it n[illegible]y be added that only a few have been [illegible]. The principle upon which these machines do their work is very similar, but they differ widely in effectiveness. The action of the fan when either vertically or horizontally fixed is proportional to the amount of resistance which air is capable of affording to the vanes when made to revolve rapidly; and that resistance being proportional to the surface of the vanes exposed and the velocity of revolution, they are necessarily made of large diameter, and worked at high speed. Atmospheric variations exercise a greater influence upon fan action (that is, the common radial open vane fan) than any other mechanical appliance. The less the density of the air the less will be displaced by the vanes of the fan, as these machines are not adapted for close casing to prevent the air from escaping back. Several of very large diameter have been erected, but they are not so effective as those machines which work on the air-pump principle. Guibal's fan differs from the ordinary radial vane fans by being enclosed in a casing, so that the principle of displacement is combined with that of the resistance of air to rapidly revolving vanes. This fan has eight vanes or arms, about 10 feet wide, which are enclosed in a casing provided with an arrangement for altering the supply of air exhausted according to circumstances. The Guibal fan is usually made of large diameter, some of them being 30 feet, and this fan bids fair to become one of the favourite mechanical appliances for generating ventilation currents. The simplicity of its construction and its non-liability to get out of order, together with its effectiveness, render it well suited for the purpose.

Two machines which are somewhat on the fan principle are those of Fabry and Lemielle. Fabry's machine consists of broad vanes revolving in opposite directions, and so constructed as to effectually act by displacement, and it does not require high velocity. Lemielle's machine is one of ingenious and peculiar construction, being a drum placed eccentrically in a large chamber, and provided with shutters so arranged as to expeditiously remove the air during its revolution.

Numerous ventilators on the air-pump principle have long been in use for mine ventilation. A very large machine was designed by Mr. Nixon, and has been at work for many years at the Navigation Colliery, Aberdare. It consists of immense rectangular chambers in which pistons travel on wheels. The chambers are fitted with flap shutters for intaking, and allowing of the expulsion of air. It is, in fact, an air-pump on a large scale. There is a considerable loss of air through the necessity of having so great a number of regulating shutters, but the immense size of the machine overcomes this deficiency, and ample ventilation can be obtained with it.

Mr. Struvé, of Swansea, has devised a ventilator on a similar principle to that of Mr. Nixon, with the exception that, instead of a piston, a gasometer, rising up and down vertically in water, takes its place. Flap shutters are used for the intake and exit of the air. Two gasometers are employed, one making the down-stroke, while the other makes the up-stroke.

In spit [illegible] ntion which has of late years bee [illegible] itilation, it does not appear [illegible] been removed, and the cry of 'air! more air!' is still to be heard. The reason of this is probably to be looked for more in the internal arrangements of a colliery than in the means employed to ventilate. The furnace is used in shallow as well as in deep mines, and it is to be feared that there is not, in many instances, sufficient power at command to overcome and successfully combat the influences to which ventilation is subservient. The form of furnace used is of the most simple construction, and we are of opinion that if experiments were carried out with a view of trying the effect of using such as would expose the air to a greater and more effectual heat, even at the expense of causing the current to traverse smaller apertures, that more power could be obtained. By increasing the power, and, what is more effective, by removing as much as possible all obstructions, and keeping the airways as large as is consistent with good and safe working, the ventilation would be greatly increased.

Friction of Air in Mines.

When the pressure required to overcome any given resistance is a known quantity, or easily determinable, very little trouble is necessary in order to calculate the equivalent of that resistance. All bodies have weight, and air has weight, and the power required to induce a quantity of air through the galleries or headings of a mine will be proportional to the weight of the air, at least, this is the generally accepted theory. It is a known fact that under all conditions a lighter gas will travel quicker, under the same amount of pressure, than a heavier one;

that is to say, atmospheric air would not give rise to so much friction in travelling through a mine as an atmosphere of carbonic acid would. There is, however, one great difference with regard to the density of the gas itself—for instance, we have observed, page 84, that Graham discovered in his experiments on the transpiration of gases, the remarkable fact that air or a gas of double density was transpired at a double velocity. Whether this law holds good in the galleries of a coal mine of sufficient length to measure 4,000 times in ratio to the diameter is a question which we think is not settled, or at least not proved to the contrary. Atkinson regards it otherwise, and states that air of double density gives rise to a double amount of friction, and we think this theory is usually accepted as correct in reference to the friction of air in mines. One thing is certain, however, that barometric depression exercises an influence on ventilation which is quite inexplicable, because, as we shall show further on, its influence should be confined entirely to the expansion of gaseous mixtures, and the inpour of fire-damp. We have already noticed the effect of barometric fluctuations upon the ventilating current so far as their cumulative effects are concerned, but these are somewhat modified in the considerations which follow.

The air in travelling through the galleries of a mine rubs against all exposed surfaces, and this rubbing gives rise to what is called *friction*. If one-tenth of the power spent upon circulating air in a colliery be sufficient, as in many instances it is, to give rise to the velocity or travelling rate of the air in the [illegible] he power must be expended in overcoming the resistances which the air meets with in traversing the mine. Thus $\frac{9}{10}$ or its equivalent is generally considered as the power required to overcome the *friction*, and it is, doubtless, a simple way of regarding it. Correctly speaking, however, *resistance* is a better term than *friction*, as it can scarcely be said that this $\frac{9}{10}$ of the power is expended solely in overcoming friction. If a mine had only one air-course running in a straight line, and there were neither short turns, doors, brattices, nor stoppings, then whatever force or pressure was required to send a current of air through it of known quantity travelling at a known rate would represent the power expended upon friction, less that which would give rise to the velocity. When, however, air is made to circulate, as it is in a mine, through winding passages, around sharp corners, and oftentimes against the dead face of a gallery or the working face of coal, as the case may be, the resistance or force of impact is more detrimental to the velocity than that which would be caused by a very large rubbing surface running parallel to the travelling direction of the air; and if this loss of velocity is regarded as due to the friction against rubbing surface, then the equivalent of such friction would bear little or no ratio at the various points in the workings of a colliery.

Air, in travelling at a high velocity around sharp corners, strikes the elbow of the turn and rebounds in a manner similar to an indiarubber ball when thrown against a hard surface, and offers naturally considerable resistance to the particles of air immediately following, and which in their turn undergo the same rebounding motion. The loss of power will be proportional to the square of the velocity or travelling rate. If the equivalent of friction for every foot of rubbing surface was one unit of power in the straight airways, the *equivalent* of friction for every foot of exposed surface around a sharp corner or dead end would be at least 10 units, especially, if the velocity were considerable. It is, consequently, a matter of great difficulty to arrive at, even approximately, any decimal figure which shall represent the equivalent of friction in the galleries of a coal mine, as there are so many turns, so many doors, brattices, and obstructions, not to mention the great irregularities of the airways themselves.

Until of late years, when the advantage of splitting the air-current into separate air-courses has been fully recognised, all the air had to travel for great distances through one circuitous route. When the air left the bottom of the downcast shaft, the velocity of the current would not be as great as it is now, owing to the loss due to the friction encountered throughout several miles of one continued route. This difference would be due to the greater velocity of the air in the one airway than that of the air in the split air-courses. It will be as well to describe simply some of the laws which bear upon the friction of air before proceeding further.

Any given quantity of air travelling at a known velocity in airways of the same size will meet with equal resistance, or give rise to equal friction, provided the initial weight or density of the air is the same.

If the ventilating [illegible] is split or divided into four sepa[illegible] for comparison sake) take equal quantities of air travelling at equal velocities, the power expended in circulating the air in one or all of the air-courses will be proportional to the square of the velocity or travelling rate.

The lower the travelling rate is, and the greater the number of splits or separate air-courses, the less power will be expended in circulating any given quantity of air, but the number of such air-courses must be regulated by the diameter of the shaft and the ventilating power at command, as the velocity must not be too much reduced, else the diffusive and sweeping power of the current will be insufficient to mix with and carry off the mine-gases, etc.

Variations of temperature and barometric fluctuations exercise a small but perceptible influence upon friction, by lessening or augmenting the weight of the air. From the table, page 282, it will be seen that 100 cubic feet of air at 50° weigh 7·790 lbs. (bar. 30in.), and if the temperature be raised to 60° F., 100 cubic feet will weigh 7·641 lbs. when the barometer stands at 30 in. If the barometer lowers 1 inch when the temperature is at 60° F., the 100 cubic feet of air will weigh 7·387 lbs., so that a rise of temperature from 50° to 60° F., accompanied by a simultaneous lowering of the barometer one inch, would lessen the weight of the air by 1-19th part. But the air in a mine becomes only slowly heated, and the temperature of the workings is not very sensible to the local variations on the surface.

It will be seen, however, taking the friction to be inversely as the density, that some of the influence which variations of temperature exercise upon the total weight of the air column in the downcast shaft is modified by the lesser amount of friction incidental upon the lighter air travelling through the workings. To illustrate this more fully, an instance is given on page 286 showing the effect of 40° F. of temperature upon the ventilating power, and we will compare this with the effect of 40° of temperature upon friction. In the case of the pit 1,000 feet deep, when the temperature in the downcast was 40° F., with the barometer standing at 30 in., and the temperature in the upcast 200° F., the difference in the weight of the air columns was 19·22 lbs. —the total ventilating power. By raising the temperature to 80°, or high summer heat, the difference in the weight of the air columns was 13·35 lbs., or a loss of 5·87 lbs. of the total pressure, or nearly a third of the total pressure if the temperature in the upcast remains the same. Now the weight of a cubic foot of air at 40° F., bar. 30 in., is ·07945 of a lb., and the weight of a cubic foot of air at 80° F. is ·07358 of a lb. The difference between ·07945 and ·07358 is ·00587, which is less than $\frac{1}{13}$ part of ·07945. If, therefore, 18 lbs. out of the 19·22 lbs. were expended in overcoming the friction and resistance in the ventilating current, then the effect of a difference in temperature of 40° F., taking the example given as representing the limit of variation between cold winter weather and a hot summer's day, would decrease the ventilating *power* by about $\frac{1}{3}$ of the total amount, when the decreased friction resulting in consequence would only compensate for $\frac{1}{13}$, that is provided the same quantity of air was travelling. If the ventilating power became less, as it would from the effect of such an increase of temperature, then the quantity of air travelling through the mine would not be so great, consequently the decrease of friction would not compensate for more than $\frac{1}{5}$ of the total loss.

It is not assumed, however, that such a variation of temperature, viz., 40° F., will take place suddenly, or that *the workings* at any time or throughout the year differ so much in temperature; on the contrary, the temperature of the mine itself even in the coldest day in winter is not materially altered, as it is removed apart from local influence which never extends many fathoms below the surface. The galleries themselves do vary somewhat according to the temperature of the air entering the downcast, and the return air as it finally reaches the bottom of the upcast will, in some degree, remain dependent upon that of the intake in the downcast. Variations of temperature do affect, to a sensible extent, the ventilation of coal mines, more especially those using furnace power, but also more or less all those where ventilating machines are employed, for the reason that in winter the temperature of the air in the downcast is considerably below the mean temperature of the mine, and the difference in density implies power of ventilation.

Assuming again the correctness of the law, that the friction of a gas or air increases with its density, the influence exercised upon the ventilating current by barometric fluctuations is nearly balanced by the lesser friction. The air column in the downcast would be reduced in density $\frac{1}{30}$ if the barometer lowered one inch, as also the air column in the upcast; or, in other words, $\frac{1}{30}$ of the total ventilating power would be lost by the lowering of the barometer one inch, but as about $\frac{9}{10}$ of the total power would be expended in overcoming the friction and resistance which the air encounters, and that friction is lessened $\frac{1}{30}$ by the lighter character of the air, it follows that barometric depression does not seriously affect the ventilating current. But barometric depression does apparently affect the ventilating current in a sensible degree, and this has yet to be accounted for, and we ask the question, Does the friction vary inversely as the density?

The power required to ventilate a colliery, or circulate a given number of feet per minute, will depend upon the extent of the rubbing surface and the travelling rate of the air. If through an airway five feet square 10,000 cubic feet of air per minute were circulating, the velocity or travelling rate of the air would be 400 feet per minute, as,

$$\frac{10{,}000}{5 \times 5} = 400$$

If the airway were 10 feet square with 10,000 cubic feet of air per minute circulating, the velocity would be 100 feet per minute; and in all cases where the airway would be square, the rubbing surface would be naturally four times one of its sides, or in the cases cited, $4 \times 5 = 20$, and $4 \times 10 = 40$ feet. The rubbing surface in the small airway is one-half that in the larger one, but the area of the large one (100 feet, or 10×10) is four times that of the small one ($5 \times 5 = 25$), so that the velocity of the air in the large airway is, as we have seen, only $\frac{1}{4}$ that in the small one. As the power required to overcome any friction or resistance varies according to the square of the [illegible] avelling rate of the body encountering the resistance, it follows that, the velocity being four times as great in the small airway as in the large one, it will take 4 × 4 = 16 times as much power to overcome the difference of velocity in order to circulate the 10,000 cubic feet of air per minute in the small as in the large airway. In order to find the total power expended in circulating an equal quantity of air in the small airway as in the large one, it must be remembered that 16 times as much power will be spent upon $\frac{1}{4}$ of the area of the large airway;—this represents 4 × 16 = 64 times the power, but as the rubbing surface in the small airway (20) is only half as much as in the large airway (40), then $\frac{64}{2} = 32$, so that it will take 32 times as much power to circulate the same quantity of air in the small as in the large airway.

In all instances the rubbing surface is calculated by adding the sum of the sides, top, and bottom of an airway. An airway 6 feet by 4 feet would expose 6 + 6 + 4 + 4 = 20 feet, and an airway 5 feet × 4 feet would expose 18 feet of rubbing surface per foot run of the heading.

We have already pointed out the difficulty of determining the equivalent of friction upon each square foot of exposed surface in the workings of a colliery, by reason of the obstructions and increased resistance offered by the winding nature of the workings, and the sharp corners which the current has to turn round. Experiments have been carried out with a view to arrive at the equivalent of friction upon a square foot of surface, and this has been determined by observers at home and abroad with pipes having their inner or rubbing surface of different materials, but the results obtained do not throw much light upon the friction of air in mines. The results of some of these experiments are given in a table in Atkinson's paper, read before the Manchester Geological Society, and since published as a treatise, 'On the gases met with in coal mines and the general principles of ventilation;' and a capital treatise it is. In the table referred to there are some discordant figures, such as, for instance, what is termed the co-efficient of friction of air travelling at the rate of 1,000 feet per minute in new and clean sheet iron pipes is calculated at from ·10583 of a foot of air column to ·06773 of a foot, while the co-efficient of friction in rusty sheet iron pipes was found by another observer to be ·02752 of a foot of air column of the same density as the flowing air. These results do not harmonise.

Atkinson, without, however, attaching much importance to the determination, selected ·26881 of a foot of air column of the same density as the flowing air as the coefficient or equivalent of friction; but the following example of the power required to ventilate a colliery will probably render it evident that there is not much dependence to be placed upon the result. A colliery has four air-courses which average 6 feet × 5 feet, and which in the aggregate measure 37,000 feet in length: the velocity of the air travelling is 200 feet per minute. The above figures represent only the galleries and workings of a colliery, and do not embrace the shafts. The rubbing surf[illegible]e $5+5+6+6=22$, which, multiplied by 37,0[illegible] 814,000 feet. The co-efficient of fri[illegible], is for air travelling at the rate of 1,000 feet per minute, so in the instance given the velocity is only $\frac{1}{5}$ or ·2 of the co-efficient, but the friction being as the square of the velocity, we have:—

$$\frac{\overset{\substack{\text{Co-efficient}\\\text{of friction.}}}{\cdot 26881} \times \overset{\substack{\text{Square of}\\\text{velocity.}}}{(\cdot 2 \times \cdot 2)} \times \overset{\substack{\text{Rubbing}\\\text{surface.}}}{814{,}000}}{\underset{\text{Area of section.}}{30}} = 291\cdot 748 \text{ feet of air column.}$$

If we take as a reasonable temperature that the air was 50° F., and the barometer as registering 30 in., then 1 cubic foot of air weighs ·07791 of a lb., and $\cdot 07791 \times 291\cdot 748 = 22\cdot 73$ lbs. per square foot as the pressure required to overcome the friction, and this, with, say, $2\frac{1}{2}$ lbs. for the shaft resistances and 2 lbs. for velocity, will give 27 lbs. as the total pressure required to ventilate a colliery under the circumstances enumerated, which, we scarcely need add, is a much greater pressure than can be obtained in ordinary coal mines. Now the quantity of air per minute travelling through the colliery in the instance above given would be anything but excessive, thus —there are four air-courses 6 feet by 5 feet, and the velocity is 200 feet per minute, then,

$$4 \times 6 \times 5 \times 200 = 24{,}000 \text{ cubic feet per minute.}$$

In the experiments which have been carried out in order to arrive at the equivalent of friction, it is possible that the primary force in generating the velocity was also included, and that this was greater than it should have been. However it is an interesting subject, and one which would repay further investigation.

Surrounded as these determinations are with very considerable difficulties, and governed as they must be by physical laws, every precaution should be taken so as not to estimate and record as friction the loss of power due to collateral causes; but the circumstances which have been mentioned in connection with this subject will always render it difficult, if, in fact, not next to impossible, to arrive at a correct equivalent of friction for a given exposed surface.

A careful measurement of the area and length of the air-courses, allowing as near as possible for the irregularities, would afford much evidence on this point, and these, compared with the temperature and ventilating pressure, would give the means of arriving at something like practical conclusions.

In order to find the equivalent of friction, divide the total pressure by the product of the square of the velocity multiplied by the total surface exposed.

It is not intended to enter into details upon the underground arrangements in reference to the size and number of airways, as these are considerations out of the province of the author. The advantage to be gained by dividing or splitting the air into several air-courses depends upon the fact that whereas the friction only increases according to the actual surface exposed, it increases not only according to the velocity or travelling rate of the air, but actually according to the square of the velocity; in other words, if in a gallery air travelling at the rate of 100 feet per minute meets with a resistance requiring 5 units of a lb. pressure per square foot to overcome that resistance, then if the velocity be raised to 200 feet per minute it will require not twice 5 units, but,

$$2 \times 2 \times 5 = 20 \text{ units of a lb. per square foot.}$$

In order to make the most of the ventilation wer, the velocity should be reduced as far as is nsistent with the size of the shaft and the main-nance of sufficient sweeping power in the air-rrents.

One great advantage which is obtained by the plitting of the air-currents into separate air-courses s, that in case of an explosion the after damp is nuch localised, and the value of such arrangements n fiery mines cannot be overrated.

APPENDIX.

THE AFTER-DAMP OF EXPLOSIONS IN COAL-MINES.

(Reprinted from 'Iron,' February 13, 1875.)

THE causes of explosions in coal-mines, and the best methods of preventing their occurrence, have been made the subject of careful consideration and investigation, and the mining world has long ago come to the conclusion that efficient ventilation is the only safeguard and prevention. Still, explosions happen, and probably will happen, and the best-ventilated colliery is not absolutely proof against them.

This has been repeatedly brought forward by eminent mining authorities, who have shown that any working portion of a mine may become almost instantaneously filled with an explosive mixture, derived from sources over which there is often little control—as, for instance, by the sudden outburst of gas from a strong blower—and that such mixture may, unfortunately, be fired under unforeseen circumstances.

It must not be inferred from these remarks that all collieries are liable to become filled with explosive mixtures, and the above observation applies, in fact, only to those collieries which are situated in the fiery or marsh-gas zone, as it is sometimes termed, of the North of England and of the South Wales basins.

Much has been done of late to insure a thorough practical and scientific system of ventilation, and the various, as well as ingenious, methods devised for the purpose of conveying, regulating, dispersing, and dividing the currents of air are a sufficient proof of the attention which has been bestowed upon this branch of mining.

It is somewhat strange, however, that up to the present time there is no work on mining which gives any insight into what actually transpires at the moment of explosion; and our knowledge of the products of combustion, and of the conditions under which an explosion takes place, as well as of the limits of an explosive mixture, is far from being perfect.

It is true such knowledge would not materially aid us in preventing the occurrence of explosions. The frightful loss of life which they entail should, however, of itself awaken a desire to make ourselves acquainted with the conditions under which death ensues, whether by burning, suffocation, or other cause, and if possible to devise some method of reaching the sufferers who, untouched by the ignited marsh-gas, are nevertheless doomed to death from the effects of the products of combustion.

Tables have been constructed by able mining authorities showing the proportion of air required by marsh-gas for its complete combustion. Theoretically this is a matter of no difficulty, since twice its volume of oxygen is the necessary quantity. And as atmospheric air contains 20·88 per cent., or rather more than one-fifth of its volume, the requisite amount of oxygen for the complete combustion of one part of marsh-gas will consequently be furnished by 9·5 parts of air. It is also as easy to tabulate the ultimate products of the combustion of this mixture, viz., carbonic acid, water, and nitrogen. But to lay down a rule wherefrom to calculate the percentage composition of the resulting products of an explosion in a mine, and to point out that a given number of parts of air and [illegible]s give rise to the most severe or deadly explosio[illegible]ly appear fallacious. Tables of this kind have been published, and are used by colliery officers. But to arrive at something like a correct idea we must take into consideration what practically happens when an explosion takes place.

It is evident that previous to an explosion in a single heading, gallery or galleries, there exists at the time—in the field of such explosion—marsh-gas and air mixed *in every proportion*, varying from 1 part of fire-damp to 99 parts of air, or from 99 parts of fire-damp to 1 part of air. There will be found, in fact, mixtures of these gases in proportions in which they will readily explode, as well as in proportions in which they do not explode.

It is difficult to define the limits within which a mixture of these gases remains inexplosive when in contact with a readily explosive atmosphere which, by some accident, may be fired. From the experiments of Davy, Henry, Bischof, and other eminent authorities, we are well acquainted with the theoretical proportions of marsh-gas and air which will cause an explosion, or ignite under ordinary conditions of temperature, &c., in a mine, provided that the fire-damp consisted entirely of marsh-gas. As experiments performed in the laboratory are almost invariably carried on with pure marsh-gas, the results are probably higher than those which would be obtained from fire-damp; for marsh-gas, either when evolved from the working face of coal, or from blowers, seldom exceeds more than 97 per cent. of the volume so given off.

It has already been stated that when 9·5 parts of air are mixed and exploded with 1 part of marsh-gas, the whole of the oxygen present is consumed, carbonic acid and water being formed.

Owing to the strong currents of ventilation passing through a mine, the air is, however, always charged with floating particles of coal, incidental upon the process of working: coal ground into fine powder by the wheels of the trams, horses' feet, &c. Hence, it is conceivable that very little oxygen may be left unconsumed, even if 13 parts of air be mixed with 1 part of fire-damp, which is probably the theoretical explosive limit of a mixture of fire-damp with air.

Davy's experiments proved that mixtures of marsh-gas with air do explode, even if the oxygen present be insufficient for complete combustion; and he has left it on record that when 1 part of this gas, mixed with 6 parts of air, was exploded by an intense electric spark, an expansion of volume resulted. Up to the present time it has been taken for granted that mixtures of marsh-gas with less than 9·5 parts of air will explode, and that carbonic acid and water are formed, as much of the hydrocarbon being broken up as the oxygen will allow, the excess remaining unaltered.

Doubting the correctness of this generally-accepted creed, and guided by the results of Davy, I was led to make some experiments in June last in the gas laboratory of the Royal College of Chemistry, South Kensington, upon a sample of gas which, on analysis, was found to contain 97 per cent. of marsh-gas, and I observed that a totally different reaction occurred.

Being engaged at the time, however, in a series of experiments on the gases enclosed in coals from the South Wales basin, I postponed the further investigation for some future occasion. In the meantime Dr. Meyer, a German chemist, has published in the November number (1874) of the *Journal für Praktische Chemie* the results of his investigation of this hydrocarbon, as well as of acetylene and hydride of ethyl when mixed and exploded with oxygen in proportions for incomplete combustion.

The results obtained by Meyer agree in all respects to those which I had found, and the law which he deduces is entirely borne out by my experiments. Meyer gives the data of two analyses which show that when marsh-gas is mixed and exploded with oxygen in equal proportions, as well as in the proportion of 8 of the former to 9 of the latter, the whole of the hydrocarbon is broken up, and carbonic acid, water, carbonic oxide, and hydrogen are formed; and he concludes that, in all cases of incomplete combustion, marsh-gas is nevertheless entirely broken up, and that if mixed and exploded with half its volume of oxygen, carbonic oxide and free hydrogen only are formed. I have found, however, that marsh-gas mixed with half its volume of oxygen does not readily explode. The experiments which I made with larger volumes of oxygen, such as mixtures containing 15 and 17 parts respectively, with 10 of marsh-gas conform likewise to this observation, viz., that the whole of the carbon of the marsh-gas combines with oxygen to form carbonic oxide and carbonic acid, while the affinity of the hydrogen for the oxygen increases, more or less, according to the quantity of oxygen present.

A general opinion has hitherto prevailed among chemists that the affinity with which hydrogen combines with oxygen to form water is quite equal, if not superior, to that of carbon to form carbonic oxide or carbonic acid. Bunsen has shown that when a mixture of carbonic oxide and hydrogen was exploded with a quantity of oxygen insufficient for complete combustion, equal proportions of these gases were respectively converted into carbonic acid and water. This is not the case, however, with marsh-gas, as from the preceding and following experiments the superior combining affinity of the carbon over that of the hydrogen of the marsh-gas will be clearly shown.

Still the relative affinities of these gases do not remain constant, as the following experimental deductions will illustrate:—

1. When the proportion of oxygen in a mixture does not exceed half the volume of the hydrocarbon, no hydrogen is consumed on explosion; the residual gases consist of carbonic oxide and hydrogen, the latter gas occupying twice the volume of the former.

2. The superior affinity of carbon manifests itself when

10 parts of marsh-gas are exploded with 17 parts of oxygen, as the remaining gases contain *some* hydrogen, while the *whole* of the carbon combines with oxygen to form carbonic acid and carbonic oxide.

3. When the oxygen mixed with marsh-gas *nearly* reaches the proportion of 2 parts of the former to 1 of the latter—which is the requisite amount for complete combustion—the *whole* of the hydrogen is transformed into water, while twice as much carbonic oxide remains as will correspond to the deficiency of oxygen.

From the results of numerous experiments it would appear then that when marsh-gas is ignited in a mine with 4·5 times its volume of air, only 10 per cent. of its carbon forms carbonic acid and 90 per cent. carbonic oxide, a little hydrogen at the same time being converted into water, while the greater part remains free; and it is highly probable under the favourable conditions of temperature, &c., which exist at the moment of explosion that large volumes of marsh-gas when mixed with small proportions of air—say 3 parts, for instance—are entirely broken up into carbonic oxide and free hydrogen.

With 5 volumes of air the carbon of the marsh-gas forms 13 per cent. of carbonic acid and 87 per cent. of carbonic oxide; with 6 volumes of air, about 20 per cent. of carbonic acid, and 80 per cent. of carbonic oxide, the latter gas decreasing as the oxygen increases, until with 9·5 parts of air carbonic acid and water only would be formed, if it were not that the floating particles of coal, ignited by the flame passing through the explosive mixture, consumed a portion of the oxygen. The volume of carbonic oxide generated during an explosion must therefore be very considerable, especially when the percentage of marsh-gas is high.

Hydrogen gas in large quantity is also liberated, as every volume of marsh-gas which is broken up sets free twice its volume of hy[illegible] y a small portion of this is converted into w[illegible] ygen present does not much exceed half the volume of the marsh-gas. When 12 volumes of this gas are exploded with 20 volumes of oxygen, nearly the whole of the hydrogen is consumed, the residual gases consisting for the most part of carbonic acid and carbonic oxide.

It will be observed that the larger the bulk of marsh-gas which is mixed with less than 9½ parts of air, the more serious will be the results of the after-damp, and it is probable that after every explosion the remaining gases contain as much, or even more, than 3 per cent. of carbonic oxide in that portion of the mine which is filled by the ignited gases. Diffusion and air-currents carry this poisonous mixture throughout the mine, and fill the main galleries leading to the mouth of the down-cast shaft, thus cutting off every chance of escape, unless the main airways remain undamaged, and the ventilation unimpaired.

The fatal effects produced by after-damp have long been an enigma to practical miners. It may readily be understood that the force of an explosion is tremendously powerful, as is proved by the after-appearance of that part of the mine where the explosion happened. It can also be imagined that the unfortunate miners in, and proximate to, the ignited mixture, have little chance of escape, the carbonic acid which is formed, together with the nitrogen which is left, being sufficient, in the absence of oxygen, to finish by suffocation the deadly work which the fire and force of the explosion have begun.

But it is too well known that the fatal effects of the after-damp are not confined to the galleries or headings in that part of the mine where the explosion took place, but also that very many lives are constantly lost in such parts of a mine as are far removed from the scene of the explosion, and in such parts also, where, in spite of the explosive force, which crushes and blows down the doors used for dividing the ventilating currents, much air will have been mixed with the products of combustion so as to dilute them. It has often been observed by parties who have descended in search of the victims that the lamps carried down with them still continued to burn brightly, while many of the explorers have fallen insensible, and have been borne back with difficulty by their comrades. We have also instances recorded of dead bodies being found after an explosion with lamps burning by their side.

Hitherto carbonic acid, even when mixed with much air, has been looked upon as the cause of the fatal effects produced; but is carbonic acid really poisonous? Carbonic oxide, we know, is poisonous in the highest degree, and 1 per cent. of this gas is sufficient to cause death when breathed for a very short time even.

Leblanc published in the 'Annales de Chimie et de Physique' some very interesting and valuable experiments upon this gas; and the following two examples taken from the above publication, will, I believe, be quite sufficient to show how probable it is that the fatal effects produced in the instances above related were caused almost entirely by carbonic oxide. An atmosphere generated by burning charcoal in a close room was found, on analysis, to contain ·54 per cent. of carbonic oxide, 4·61 per cent. of carbonic acid, 19·19 per cent. of oxygen, and 75·66 per cent. of nitrogen. A dog which was kept in and compelled to breathe this mixture died in twenty-five minutes from the time when the charcoal was ignited, whereas a dog survived which had been shut up for three-quarters of an hour in a mixture of carbonic acid and air containing no less than 30 per cent. of the former, when he was removed at the expiration of the above time.

ON THE GASES ENCLOSED IN COALS FROM THE SOUTH WALES BASIN, AND THE GASES EVOLVED BY BLOWERS AND BY BORING INTO THE COAL ITSELF.

PART I.

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THE composition of the gases enclosed by coal has attracted some considerable attention of late. Investigations have been conducted by Dr. Ernest von Meyer, in Professor Kolbe's laboratory at Leipzig, both upon English and upon German coals, from some of the principal coal basins, the results of which have been published in the *Journal für Praktische Chemie* [2], v, 144-183; 407-427, and vi, 389-416, and an abstract of which will be found in the 'Chemical Society's Journal' [2], x, 798 and 801, and xi, 483. The eight samples of English coal which were analysed were obtained from the Newcastle and Durham coal-fields, but no information was given whether they were bituminous or anthracite. It appeared to me therefore of sufficient importance to examine the deposits of anthracite and of other coals from the Great South Wales basin.

Meyer undertook his experiments for determining the quantity and percentage composition of the gases actually enclosed within the pores of the coals, with a view of throwing some additional light upon the natural processes which were at work in their formation, and upon the natural history of coal generally. With the view of extending these researches to the gases of the coals from the South Wales basin, and also of obtaining information on the conditions attending preceding colliery explosions, I, at the suggestion of Mr. Valentin, took up this work, the results of which I now beg to submit to the Society.

It is obvious that the results obtainable in an investigation of this nature are largely dependent upon the methods employed. The analysis of gases has now become of comparatively easy and rapid execution, thanks to Frankland's gas apparatus, improved and modified by McLeod, an apparatus of which I cannot speak in too high terms of satisfaction. To those who have been in the habit of working by Bunsen's method some of the figures of the subjoined analyses will appear somewhat incredible, owing to the small excess of oxygen I frequently used in exploding marsh-gas. This, in fact, is possible only with an apparatus in which the gases can be very considerably rarefied.

The gases enclosed in the eight samples of English coal analysed by Meyer were those of ordinary mine gas, and consisted of carbonic acid, marsh-gas, oxygen, and nitrogen. In no single case did he meet with any hydrocarbon other than marsh-gas. In a few coals from German sources, however, Meyer observed also hydride of ethyl and olefiant gas. I have invariably looked for these gases whenever the figures of a preliminary analysis gave any indications of their presence, but have rarely met with more than traces in the coals which I examined. I also confined myself, for the present, to the coals from the South Wales basin—bituminous, steam, and anthracite—which had never before been investigated, and with which a previous practical acquaintance had made me familiar. I made it a point to procure the samples in lumps about 10 inches cube, and to submit them to analysis as speedily as possible.

In the classification of the numerous samples of coals I have adopted the three classes: *bituminous*, sometimes called 'house coals;' *steam coal*, a class intermediate between bituminous and anthracite, a coal for which the South Wales basin is famous; and lastly, *anthracite*.

The following table gives the names of the different samples of coal, the collieries and districts whence they are derived, and the depth from the surface :—

No. of Sample	Seam	Colliery	Kind of Coal	District	Depth from Surface
1	No. 1	Plymouth Iron Works	Bituminous	Merthyr	Level
2	No. 3	" " "	"	"	"
3	No. 3	Cwm Clydach	"	Rhondda	—
3*a*	Abergorki	Bute, Merthyr	Semi-bituminous	"	Level
4	2 ft. 9 in.	" "	Steam	"	100 yards
5	Upper 4 ft.	Navigation	"	Aberdare	400 "
6	" 4 ft.	Dunraven	"	Rhondda	206 "
7	" 4 ft.	Cyfartha	"	Merthyr	180 "
8	6 ft.	Bute, Merthyr	"	Rhondda	140 "
9	6 ft.	Dunraven	"	"	225 "
10	9 ft.	Duffryn	"	Aberdare	—
11	Bettwys	—	Bituminous	Ogmore	140 yards
12	Lantwit	—	"	"	—
13	—	Bonville's Court	Anthracite	Pembrokeshire Coal-field	—
14	—	Watney's	"	Carmarthenshire Coal-field	—

On looking carefully over Meyer's paper, and especially on trying to reconcile certain anomalies which occur in his analytical results, I was led to question the accuracy of his method of obtaining the gases from the coals. Meyer introduced small pieces of coal, amounting to from 200 to 400 grams, into a glass flask which was immediately filled up with hot de-aërated water, and boiled as long as any appreciable quantities of gases were given off. The delivery-tube was likewise filled with boiled water and fitted by a caoutchouc plug into the mouth of the flask. The gases were collected over boiled water in a number of tubes, and submitted to analysis by Bunsen's method. To those who know the difficulty of removing the whole of the gases from water, even under diminished pressure, it will at once be apparent that the same difficulty would be encountered, if possible, on an increased scale, by endeavouring to collect in this manner the gases evolved from coal, not to speak of the danger and liability to loss from the solubility of the carbonic acid in the water, on transferring the mixed gases to the mercury trough and the subsequent removal of the water from the tubes.

After various preliminary endeavours to devise a more accurate and at the same time more expeditious method of analysis, I fixed at last upon one which I found to answer well. It may be described briefly as follows :—

Slices of coal were sawn out of the middle of the large cubes, and a strip about $\frac{5}{8}$ inch in thickness and 6 inches to 8 inches in length was next cut from the middle of this slice, the edges rounded off, so as to make it slide readily into a glass tube of the proper diameter.

The coal was brushed with a feather to remove any adhering dust, and speedily placed in the glass tube, one end of which had previously been drawn out into a long narrow neck so as to form a connection with the Sprengel mercurial pump. The other end was then sealed off before the blowpipe, at a sufficient distance from the coal to prevent any material rise in temperature. The usual water-joint connection was then made with the Sprengel pump, the air exhausted as quickly as possible, until almost a perfect vacuum had been obtained, and the last portion of the gases which was brought over collected and subjected to analysis. Many of the bituminous and steam coals of the South Wales coal-field are of a porous nature, and far from hard or dense; and from their physical aspect it appeared probable that, on withdrawing the air from around the strips of coal, and on the formation of a partial vacuum, a large portion of the gases enclosed in the coal would escape. This was not found to be the case, however, as very little gas was evolved from any of the coals which I had occasion to examine, even when almost a complete vacuum had been obtained, and the amount of gases so given off rarely exceeded 2 or 3 c.c. per 100 grams of coal. Some of the steam and bituminous coals, which were hard and laminated, as well as the still harder and denser anthracites, evolved only traces of gas, while the enclosed gases were rapidly given off as soon as the temperature was raised. When the whole of the air had been removed, the tube containing the coal was immersed in a vessel of boiling water and kept at a temperature of 100° C. (212° F.) for about seven hours, or until the mercury pump ceased to bring over any appreciable quantity of gas. The gases thus evolved were collected in graduated tubes. From 10 to 30 grams of coal were usually employed in each experiment, according to the nature of the coal and the quantity of gas evolved, a very small quantity of anthracite being sufficient to furnish an ample amount of gas for analysis, whilst highly bituminous coals gave off so little gas that 30 grams of coals were required to yield the necessary volume. Duplicate analyses were invariably made of the gases evolved from each sample of coal, and in cases where the results of the second experiment differed from the first, a further analysis was made.

The rapidity with which the occluded gases are evolved, under a vacuum at 100° C. (212° F.) depends upon the hardness of the coal and the quantity of gas enclosed. By far the greater portion of the gases given off at that temperature is brought over by the pump during the first three hours.

Still the whole of the enclosed gases present in these coals is not withdrawn at 100° C. (212° F.) nor even at 200° C. (392° F.), and there remains a considerable quantity still imprisoned in the pores of the coals after having been kept at that temperature for hours. In a few instances I proved this by heating the coal up to 300° C. (572° F.), or close upon the point where decomposition begins to take place.

This fact appears to me of considerable importance, as it shows that Meyer can only have worked with a portion of the gases, viz., with that portion which is occluded from coal at the temperature of boiling water.

The following are the results I obtained :—

SAMPLE No. 1.—*Bituminous, from a level above South Pit, Plymouth Iron Works.*

100 grams of coal evolved 55·9 c.c. of gas at 100° C. (212° F.)

An analysis made of the last portion of gases exhausted in forming a vacuum at ordinary temperatures, gave in 100 parts :—

Carbonic acid	2·01
Oxygen	19·11
Nitrogen	78·88
	100·00

Analysis of the gas evolved at 100° C. (212° F.) :—

	Composition in 100 parts.
Carbonic acid	36·42
Oxygen	0·80
Nitrogen	62·78
	100·00

SAMPLE NO. 2.—*Bituminous, from South Pit, Plymouth Iron Works.*

This coal was probably exposed to atmospheric influences in the seam, previous to being cut.

100 grams of coal evolved 61·2 c.c. of gas at 100° C. (212° F.)

An analysis made of the last portion of gases, withdrawn in forming a vacuum, at ordinary temperatures gave in 100 parts:—

Carbonic acid	0·31
Oxygen	20·68
Nitrogen	79·01
	100·00

Analysis of the gas evolved at 100° C. (212° F.):—

	Composition in 100 parts.
Carbonic acid	16·77
Oxygen	2·72
Marsh-gas	0·40
Nitrogen	80·11
	100·00

SAMPLE NO. 3.—*Bituminous, from Cwm Clydach. No.* 3 *Rhondda.*

100 grams of coal evolved 55·1 c.c. of gas at 100° C. (212° F.)

An analysis made of the last portion of gases withdrawn in forming a vacuum at ordinary temperatures, gave in 100 parts:—

Carbonic acid	0·22
Oxygen	20·59
Marsh-gas	trace
Nitrogen	79·19
	100·00

Analysis of the gas evolved at 100° C. (212° F.):—

	Composition in 100 parts.
Carbonic acid	5·44
Oxygen	1·05
Marsh-gas	63·76
Nitrogen	29·75
	100·00

The tube containing the coal, after disconnecting from th Sprengel pump, was left exposed to the atmosphere for eleve weeks and two days, at the expiration of which it was again connected with the pump, and heated to 100° C. (212° F.) for sever hours.

An analysis made of the last portion of gases withdrawn i forming a vacuum at the ordinary temperature, gave in 10 parts :—

Carbonic acid	0·45
Oxygen	20·60
Marsh-gas	trace
Nitrogen	78·95
	100·00

100 grams of coal evolved 33·2 c.c. of gas at 100 C.° (212° F.) o the following composition :—

	Composition in 100 parts
Carbonic acid	11·10
Oxygen	7·67
Marsh-gas	9·31
Nitrogen	71·92
	100·00

SAMPLE No. 3*a*.—*Semi-bituminous, Bute Merthyr Colliery, Rhondda District.*

This coal gave off its enclosed gases very readily.

100 grams of coal evolved 73·6 c.c. of gas at 100° C. (212° F.)

An analysis made of the last portion of gases withdrawn in forming a vacuum at the ordinary temperatures, gave in 100 parts :—

Carbonic acid	2·12
Oxygen	19·01
Marsh-gas	0·85
Nitrogen	78·02
	100·00

Analysis of the gas evolved at 100° C. (212° F.) :—

	Composition in 100 parts.
Carbonic acid	12·34
Oxygen	0·64
Marsh-gas	72·51
Nitrogen	14·51
	100·00

SAMPLE No. 4.—*Steam, from Bute Merthyr Colliery; 2 ft. 9 in. Seam.*

100 grams of coal evolved 194·8 c.c. of gas at 100° C. (212° F).

An analysis made of the last portion of gases withdrawn in forming a vacuum at ordinary temperatures gave, in 100 parts :—

Carbonic acid	1·02
Oxygen	19·07
Marsh-gas	0·61
Nitrogen	79·30
	100·00

Analysis of the gas evolved at 100° C. (212° F.) :—

	Composition in 100 parts.
Carbonic acid	5·04
Oxygen	0·33
Marsh-gas	87·30
Nitrogen	7·33
	100·00

SAMPLE No. 5.—*Steam, Upper 4-feet Seam, Navigation Colliery.*

100 grams of coal evolved 250·1 c.c. of gas at 100° C. (212° F.)

An analysis made of the last portion of gases withdrawn in forming a vacuum at the ordinary temperature, gave in 100 parts :—

Carbonic acid	1·17
Marsh-gas	0·86
Oxygen	19·41
Nitrogen	78·56
	100·00

Analysis of the gas evolved at 100° C. (212° F.) :—

	Composition in 100 parts.
Carbonic acid	13·21
Oxygen	0·49
Marsh-gas	81·64
Nitrogen	4·66
	100·00

SAMPLE No. 6.—*Steam, Upper 4-feet Seam, Dunraven Colliery.*

100 grams of coal evolved 218·4 c.c. of gas at 100° C. (212° F.)

An analysis made of the last portion of gases withdrawn in forming a vacuum at the ordinary temperature, gave in 100 parts :—

Carbonic acid	0·66
Marsh-gas	2·23
Oxygen	18·51
Nitrogen	78·60
	100·00

Analysis of the gas evolved at 100° C. (212° F.) :—

	Composition in 100 parts.
Carbonic acid	5·46
Oxygen	0·44
Marsh-gas	84·22
Nitrogen	9·88
	100·00

SAMPLE No. 7.—*Steam, Upper 4-feet Seam, Cyfartha.*

This coal had probably been exposed to atmospheric influences previous to being removed from the seam, and had been taken from the pit nine days before being analysed.

100 grams of coal evolved 147·4 c.c. of gas at 100° C. (212° F.)

An analysis made of the last portion of gases withdrawn in forming a vacuum at the ordinary temperature, gave in 100 parts :—

Carbonic acid	0·49
Marsh-gas	trace
Oxygen	20·66
Nitr	78·85
	100·00

Analysis of the gas evolved at 100° C. (212° F.) :—

	Composition in 100 parts.
Carbonic acid	18·90
Oxygen	1·02
Marsh-gas	67·47
Nitrogen	12·61
	100·00

SAMPLE No. 8.—*Steam, 6-feet Seam, Bute Merthyr Colliery.*

This was, without exception, the hardest steam coal which I have examined, and it approached very nearly to the anthracites in structure and appearance.

100 grams. of coal evolved 375·4 c.c. of gas at 100° C. (212° F.)

An analysis made of the last portion of gases withdrawn in forming a vacuum at the ordinary temperature, gave, in 100 parts :—

Carbonic acid	0·51
Marsh-gas	0·98
Oxygen	20·01
Nitrogen	78·50
	100·00

Analysis of the gas evolved at 100° C. (212° F.) :—

	Composition in 100 parts.
Carbonic acid	9·25
Oxygen	0·34
Marsh-gas	86·92
Nitrogen	3·49
	100·00

This coal was broken into small pieces about the size of a walnut, and left exposed to the atmosphere for 14 weeks. A portion was then taken and subjected to 100° C. (212° F.) for seven hours under a vacuum.

100 grams. of coal evolved 112·3 c.c. of gas at 100° C. (212° F.)

Analysis of the gas evolved at 100° C. (212° F.) :—

	Composition in 100 parts.
Carbonic acid	11·75
Oxygen	2·64
Marsh-gas	54·78
Nitrogen	30·83
	100·00

SAMPLE No. 9.—*Steam, 6-feet Seam, Dunraven Colliery.*

This coal was soft and porous. This accounts in some measure for the low percentage of marsh-gas.

100 grams. of coal evolved 149·3 c.c. of gas at 100° C. (212° F.)

An analysis made of the last portion of gases withdrawn in forming a vacuum at the ordinary temperature, gave, in 100 parts :—

Carbonic acid	0·76
Oxygen	17·93
Marsh-gas	3·75
Nitrogen	77·56
	100·00

Analysis of the gas evolved at 100° C. (212° F.) :—

	Composition in 100 parts.
Carbonic acid	11·35
Oxygen	0·56
Marsh-gas	73·47
Nitrogen	14·62
	100·00

SAMPLE No. 10.—*Steam, 9-feet Seam, Duffryn Colliery.*

100 grams. of coal evolved 215·4 c.c. of gas at 100° C. (212° F.)

The last portion of air withdrawn in forming a vacuum at the ordinary temperature was lost.

Analysis of the gas evolved at 100° C. (212° F.) :—

	Composition in 100 parts.
Carbonic acid	5·64
Oxygen	0·54
Marsh-gas	82·70
Nitrogen	11·12
	100·00

SAMPLE NO. 11.—*Bituminous, Bettwys Coal, Ogmore Valley.*

100 grams. of coal evolved 24·0 c.c. of gas at 100° C. (212° F.)

An analysis of the last portion of gases withdrawn in forming a vacuum at the ordinary temperature, gave in 100 parts:—

Carbonic acid	0·22
Oxygen	20·66
Nitrogen	79·12
	100·00

Analysis of the gas evolved at 100° C. (212° F.):—

	Composition in 100 parts.
Carbonic acid	22·16
Oxygen	6·09
Marsh-gas	2·68
Nitrogen	69·07
	100·00

SAMPLE NO. 12.—*Bituminous, Llantwit.*

100 grams. of coal evolved 39·7 c.c. of gas at 100° C. (212° F.)

An analysis of the last portion of gases withdrawn in forming a vacuum at the ordinary temperature, gave, in 100 parts:—

Carbonic acid	0·31
Oxygen	20·51
Marsh-gas	0·23
Nitrogen	78·95
	100·00

Analysis of the gas evolved at 100° C. (212° F.):—

	Composition in 100 parts.
Carbonic acid	9·43
Oxygen	2·25
Marsh-gas	31·98
Nitrogen	56·34
	100·00

The tube containing the coal, after disconnecting from the Sprengel, was left exposed to the atmosphere for ten weeks, at the

expiration of which it was again connected with the pump, exhausted, and heated to 100° C. (212° F.) for seven hours.

100 grams. of coal evolved 31·2 c.c. of gas.

Analysis of the gas evolved at 100° C. (212° F.) :—

	Composition in 100 parts.
Carbonic acid	**18·62**
Oxygen	**7·94**
Marsh-gas	**7·86**
Nitrogen	**65·58**
	100·00

SAMPLE NO. 13.—*Anthracite, Bonville's Court.*

100 grams. of coal evolved 555·5 c.c. of gas at 100° C. (212° F.).

An analysis made of the last portion of gases withdrawn in forming a vacuum at the ordinary temperature, gave, in 100 parts :—

Oxygen	20·89
Nitrogen	79·11
	100·00

Analysis of the gas evolved at 100° C. (212° F.) :—

	Composition in 100 parts.
Carbonic acid	2·62
Oxygen	none
Marsh-gas	93·13
Nitrogen	4·25
	100·00

SAMPLE NO. 14.—*Anthracite, Watney's Llanelly.*

100 grams. of coal evolved, when heated for seven hours at 100° C. (212° F.) 600·6 c.c. of gas.

An analysis of the last portion of gases withdrawn in forming a vacuum at the ordinary temperature, gave. in 100 parts :—

Oxygen	20·79
Nit	79·21
	100·00

Analysis of the gas evolved at 100° C. (212° F.):—

	Composition in 100 parts.
Carbonic acid	14·72
Marsh-gas	84·18
Nitrogen	1·10
	100·00

The same portion of coal, after standing *in vacuo* at the ordinary temperature (14° C., 57° F.) for nineteen hours, evolved 56·6 c.c. of gas per 100 grams. of coal; and on being further heated in a bath of paraffin at 200 C. (392° F.) for eight hours, it evolved 993·1 c.c. per 100 grams. of coal.

Analysis of the gas evolved at 200° C. (392° F.):—

	Composition in 100 parts.
Carbonic acid	8·06
Marsh-gas	91·83
Nitrogen	0·11
	100·00

After again standing *in vacuo* at the ordinary temperature (12° C., 54° F.) for forty-one hours, 19·1 c.c. of gas per 100 grams. of coal were evolved; and when further heated at 300° C. (572° F.) in a paraffin bath, 206·5 cc. of gas per 100 grams. of coal were given off.

Analysis of the gas evolved at 300° C. (572° F.):—

	Composition in 100 parts.
Carbonic acid	1·43
Marsh-gas	98·47
Nitrogen	0·10
	100·00

The total volume of gas evolved by this coal was 1875·9 c.c. per 100 grams. These three experiments, then, show clearly that the whole of the gas present in the sample was not given off at 100° C. (212° F.) nor at 200° C. (392° F.); but at 300° C. (572° F.) the evolution ceased for some hours; and from this it may be inferred that no decomposition took place at that temperature. This is likewise proved by glancing at the composition of the respective gas volumes.

Sample No. 14.—9 grams. of this coal, taken from the centre of a large lump which had been exposed to the atmosphere for four weeks subsequently to taking the portion employed in the foregoing experiment, was introduced in small pieces into a narrow glass tube. One end of the tube was previously drawn out into a long neck to form a connection with the Sprengel, and a portion of the neck thickened and drawn out very fine for the purpose of hermetically sealing it under a vacuum. After introducing the coal into the tube, the wide end was sealed in the blowpipe flame, and the tube connected with the Sprengel and exhausted.

The coal was heated at 100° C. (212° F.) under a vacuum for twenty-one hours, and remained at the ordinary temperature for another seventy hours.

At the end of this time 65·8 c.c. of gas was withdrawn, equal to 731·1 c.c. per 100 grams. of coal.

The gas collected was transferred to a Bunsen eudiometer and measured, and the tube containing the coal *in vacuo*, after having been hermetically sealed before the blowpipe, was passed up into the eudiometer and pressed against the side to break off the point. It was left in contact with the gas for five days, after which it was filled with mercury to displace the gas, and then removed from the eudiometer. The remaining gas was then measured, and after allowing for the rise of temperature incidental upon introducing the tube into the eudiometer, &c., I found that no more than 5 c.c. of gas had become re-absorbed by the coal. This experiment was undertaken with a view to ascertain whether the gases were held by virtue of some condensing power possessed by the coal, or merely imprisoned in its pores, and held fast mechanically.

A portion of the gases evolved by the 9 grams. of coal during the first hour, heated at 100° C. (212° F.) was analysed, and also a portion of the gas collected, after heating at 100° C. (212° F.) for three hours. The following are the results of the analyses:—

Gas evolved during the first hour.

	Composition in 100 parts.
Carbonic acid	14·60
Marsh-gas	81·34
Nitrogen	4·06
	100·00

Analysis of the gas after the coal was heated for three hours.

	Composition in 100 parts.
Carbonic acid	13·91
Marsh-gas	82·45
Nitrogen	3·64
	100·00

Having given full details of the various analyses, there remains for me now only to sum up briefly the deductions which in my opinion may be drawn from them.

The gases from the three classes of coal which were analysed differ, as might be expected, both in quality and even more so in quantity. The bituminous coals when on or near the surface contain little or no marsh-gas, and the percentage of carbonic acid is usually very high. The quantity of gas which they yield is much smaller than that given off from either steam coal or anthracite. It would indeed be possible to arrive at a pretty safe conclusion as to the bituminous character of a coal, by analysing the enclosed gases, and taking into account the quantity. It will also become readily apparent that seams of bituminous coals can be and are worked all over South Wales with naked lights, as they contain little or no marsh-gas. And the few samples taken from deeper levels which contained a high percentage of the same still differ materially from the steam coals and anthracite, by giving off comparatively small quantities of gases only. The real difficulty of working these seams arises, in fact, not so much from the presence of marsh-gas as from carbonic acid. On no occasion did I meet with any carbonic oxide, however, although I looked carefully for this poisonous gas.

Steam coals evolve a much larger quantity of gases than bituminous, and their composition also differs by showing invariably a very high percentage of marsh-gas, as much, in fact, as 87 per cent. The volume of gas depends in a great measure upon the hardness and porosity of the coals, and upon the time which has elapsed since they were removed from their respective seams or veins; this latter applies equally to all coals.

Hard compact steam coals, especially those showing laminated structure, evolve a quantity of gas approaching to that given off by anthracites.

Steam coal also gives off a considerable quantity of gas at 200° C. (392° F.), after having been previously heated at 100° C. (212° F.) for some hours. The analytical data, together with those showing the composition of gases present in coal after exposure to the atmosphere for several months, were. however, unfortunately lost.

Anthracites yield by far the largest gas volumes, *e.g.*, sample 14, of specific gravity 1·35, and giving on analysis 2·67 per cent. of hydrogen, yielded from 100 grams. of coal as much as 600 c.c. of gas, when heated at 100° C. (212° F.) for seven hours. On heating it to 200° C. (392 °F.) for eight hours, close upon 1,000 c.c. of gas were obtained, whilst at 300° C. (572 °F.) a still further quantity was given off, the gas obtained amounting altogether to 1875·9 c.c. per 100 grams. of coal.

The composition of the gases evolved from anthracite closely resembles that from steam coals. The only difference appears to be that the anthracites from the western part of the coal basin occlude more marsh-gas and less carbonic acid (comp. sample 13), and that they are absolutely free from oxygen, while steam coals, as a rule, showed traces of oxygen.

Since, however, no oxygen could be found in any of the blower gases, as I shall have opportunity to show in Part II. of this paper, I am inclined to think that the small quantity of oxygen was derived from the air which diffused into the coal during the time of handling it.

It is worth observing, moreover, that the gases evolved from anthracite at 100° C. (212° F.), 200° C. (392° F.), and 300° C. (572° F.), are analogous in composition, so far as they consist of carbonic acid, marsh-gas, and nitrogen only; but that the percentage of the latter is reduced to a mere trace (in fact, within the analytical limits of error); also, that the percentage of carbonic acid decreases, leaving a gas volume consisting almost entirely of marsh-gas.

Why the heavier gases should come off first in a partial vacuum—an observation which is entirely in contradiction to the law of diffusion—I am unable to explain; for when the coal was left in connection with the evolved gases at the ordinary temperature, no material re-absorption was observed. In fact, the coal has no power to recondense the gases when once liberated.

The following table will show the quantities of gases evolved, as well as the percentage composition :—

No. of Sample	Gas evolved by 100 grammes of coal at 100° C. (212° F.), *in vacuo*	Composition of Gases			
		Carbonic acid	Oxygen	Marsh-gas	Nitrogen
	c.c.				
1	55·9	36·42	0·80	—	62·78
2	61·2	16·77	2·72	0·40	80·11
3	55·1	5·44	1·05	63·76	29·75
3*a*	73·6	12·34	0·64	72·51	14·51
4	194·8	5·04	0·33	87·30	7·33
5	250·1	13·21	0·49	81·64	4·66
6	218·4	5·46	0·44	84·22	9·88
7	147·4	18·90	1·02	67·47	12·61
8	375·4	9·25	0·34	86·92	3·49
9	149·3	11·35	0·56	73·47	14·62
10	215·4	5·64	0·54	82·70	11·12
11	24·0	22·16	6·09	2·68	69·07
12	39·7	9·43	2·25	31·98	56·34
13	555·5	2·62	—	93·13	4·25
14	600·6	14·72	—	84·18	1·10

The fact must not be lost sight of that the preceding conclusions refer only to anthracites, when examined in the laboratory; neither must it be taken for granted, because a coal contains a large volume of occluded gases, even when such gases consist mainly of marsh-gas, that the seam or vein from which it is derived is a fiery one, and one that requires great caution in working. The very reverse is indeed the case. Now, although steam coal yields less gas than anthracite, it must not be supposed for a moment that it is therefore safer to work the former. Steam coal, before being removed from the seam or vein, holds enclosed a much larger quantity of gas. Being less hard and more porous, the gas escapes from it in vastly increased quantities over that from anthracite. The volume of gas rushing out from the working face of most deep steam coals is so enormous as to be almost incredible, whilst little gas escapes from a working face of anthracite coal. The great hardness and jet-like structure of the latter accounts, in a great measure also, for the large volume of gas which it holds enclosed, and it is probable that its formation must have taken place under such immense pressure that the gases generated during the transformation of the organic matter into anthracite were not able to make their escape.

I have been led also to examine the gases given off from the working-face of coal and from blowers, and my anticipation that the composition of the occluded gases and of the mine-gases would stand in a definite and fixed relation was borne out by my experiments.

PART II.

Numerous analyses of the gases evolved from blowers, collected both in the mine as well as on the surface, have been made by Henry, Graham, Playfair, and other investigators; but, as far as I am aware, they confined themselves to the North of England coal fields.

In the 'F [illegible] e Museum of Economic Geology,' June, 184 [illegible] gave the results of many analyses, and [illegible] rbonic acid is present in mine-gas.

Previous to his investigations, the presence of this gas in blowers was open to doubt, as Graham did not detect it in the analyses which he submitted to the Chemical Society (' Memoirs of the Chemical Society,' vol. ii. p. 7). Playfair concludes that this was owing to the method employed by Graham in obtaining the gases, viz., collection over water, carbonic acid being soluble in that liquid.

The method which I adopted for collecting the blowers was somewhat similar to that by which Playfair obtained some of his samples. Others he collected over water. My method was as follows :—

The crack or rent in the rock from which the gases were evolved was carefully filled in with clay, to prevent the diffusion of atmospheric air, and a small hole was left in the centre, into which a glass funnel was introduced and made air-tight with clay. Glass tubes which had previously been drawn out at each end into a small neck were connected with the funnel by means of indiarubber tubing, and screw clamps were placed upon the indiarubber connections at both ends of the tubes.

When the blower was a strong one, it was only necessary to allow the gas to pass through the tubes for about ten minutes, in order to displace the air. But I found that in most cases it was impracticable to displace the whole of the air in this manner, as the gas found several outlets through the many cracks in the rock. I therefore applied suction by means of a double-acting syringe. When all the air had been displaced, the tubes were slightly warmed, and the clamps screwed tight; they were then taken without delay to the lamp station for the purpose of sealing the ends before a blow-pipe flame.

Being desirous of comparing the blower gases with the gas evolved by the coal won in the gallery or heading in which the blower gas was collected, a hole was drilled into the solid face of the coal itself, and the gases collected in the manner mentioned. The same method was also used for collecting those blowers which in some instances were carried to the surface of the pits.

The following are the results of my analyses :—

No. 1.—Gases obtained from the top rock of the 6-feet seam, Dunraven Colliery, Treherbert, 225 yards from the surface.

	Composition in 100 parts.
Marsh-gas	97·65
Carbonic acid	0·50
Nitrogen	1·85
	100·00

No. 2.—Gas obtained by boring into the coal, 6-feet seam, Dunraven Colliery, Treherbert, 225 yards from the surface.

	Composition in 100 parts.
Marsh-gas	97·31
Carbonic acid	0·38
Nitrogen	2·31
	100·00

No. 3. Gas obtained from the top rock of the 4-feet seam, Dunraven Colliery, Treherbert, 125 yards from the surface.

	Composition in 100 parts.
Marsh-gas	96·74
Carbonic acid	0·47
Nitrogen	2·79
	100·00

No. 4. Gas obtained from the 4-feet seam by boring into the coal, Dunraven Colliery, Treherbert, 125 yards from the surface.

	Composition in 100 parts.
Marsh-gas	96·54
Carbonic acid	0·44
Nitrogen	3·02
	100·00

No. 5.—Gas obtained from the 6-feet seam by boring into the coal, Fochriew Colliery No. 2, Merthyr District, 395 yards from the surface.

		Composition in 100 parts.
Marsh-gas		74·86
Carbonic acid		0·15
Air	Oxygen	4·69
	Nitrogen	17·75
Nitrogen		2·55
		100·00

No. 6.—Gas obtained by boring into the coal, 9-feet seam, Fochriew Colliery No. 2, Merthyr District, 454 yards from the surface.

	Composition in 100 parts.
Marsh-gas	97·37
Carbonic acid	0·42
Nitrogen	2·21
	100·00

No. 7.—Gas obtained from the 4-feet seam by boring into the coal, South Pit, Plymouth Iron Works, Merthyr, 300 yards from the surface.

	Composition in 100 parts.
Marsh-gas	95·42
Carbonic acid	0·60
Nitrogen	3·98
	100·00

No. 8.—Gas obtained from the top rock of the 4-feet seam South Pit, Plymouth Iron Works, Merthyr, 300 yards from the surface. Water oozed out, together with the gas. This accounts for the low percentage of carbonic acid.

	Composition in 100 parts.
Marsh-gas	94·84
Carbonic acid	0·10
Nitrogen	5·06
	100·00

No. 9.—Gas obtained from the top rock of the 6-feet seam, Forchammon Colliery, Aberdare District, 230 yards from the surface.

This blower contained the highest percentage of carbonic acid of any which I have examined, and, apparently, was derived from an unworked seam of coal some yards above, with which a quantity of slag or shale rich in carbonic acid may have been combined. Or the gases evolved by the seam of coal may have passed through a vein of such a shale before reaching the gallery in which they were collected. No water accompanied the gas. Several analyses of this gas were made.

	Composition in 100 parts.
Marsh-gas	95·05
Carbonic acid	4·26
Nitrogen	0·69
	100·00

No. 10.—This gas was obtained from a rent in the top rock of the 4-feet seam, Ferndale No. 2 Colliery, Rhondda District.

The rock was much broken, thus rendering it impossible to prevent atmospheric air from becoming mixed with the gas. The carbonic acid is very high in this sample.

	Composition in 100 parts.
Marsh-gas	47·37
Air	48·60
Carbonic acid	0·90
Nitrogen	3·13
	100·00

No. 11.—This gas was obtained from a heading connecting the upcast and downcast shafts, Bute Merthyr Colliery, Rhondda District, situated about 20 yards above the 2-feet 9-inch seam, and 80 yards from the surface.

This was a very strong blower, and there was no water issuing from the rock.

	Composition in 100 parts.
Marsh-gas	95·47
Carbonic	0·62
Nitroge	3·91
	100·00

No. 12.—Gas obtained on the floor of a hard heading between the 6-feet and 9-feet seams, Maesteg Merthyr Colliery, 140 yards from the surface.

	Composition in 100 parts.
Marsh-gas	95·51
Carbonic acid	1·96
Nitrogen	2·53
	100·00

No. 13.—This gas was obtained from the lamp-room, Llwynypia Colliery, Rhondda District, and is brought up to the surface for the purpose of lighting the engine-room, lamp-room, and the top of the down-cast shaft. I made several analyses of this gas, and invariably found that a small quantity of some hydrocarbon, probably hydride of ethyl, was present in addition to marsh-gas.

	Composition in 100 parts.
Marsh-gas	94·78
Hydride of ethyl	0·90
Carbonic acid	0·72
Nitrogen	3·60
	100·00

No. 14.—This gas was collected from the side of Cwm Park Brook, where it escaped in large quantity. Ystrad, Rhondda District.

	Composition in 100 parts.
Marsh-gas	95·56
Oxygen	0·11
Carbonic acid	0·35
Nitrogen	3·98
	100·00

The annexed table gives a brief summary of the preceding analyses of blowers and gases from borings.

On looking over these analytical data, and comparing the volume of carbonic acid absorbed after the combustion of the marsh-gas with the contraction in volume after explosion[1]

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[1] The calculating volumes are given in the original paper.

No. of Sample	Whether a blower, or obtained by boring into coal	Composition of the Gas				
		Marsh-gas	Hydride of ethyl	Carbonic acid	Oxygen	Nitrogen
1	Blower	97·65	—	0·50	—	1·85
2	Boring	97·31	—	0·38	—	2·31
3	Blower	96·74	—	0·47	—	2·79
4	Boring	96·54	—	0·44	—	3·02
5	"	74·86	—	0·15	4·69	20·30
6	"	97·37	—	0·42	—	2·21
7	"	95·42	—	0·60	—	3·98
8	Blower	94·84	—	0·10	—	5·06
9	"	95·05	—	4·26	—	0·69
10	"	47·37	—	0·90	10·15	41·58
11	"	95·47	—	0·62	—	3·91
12	"	95·51	—	1·96	—	2·53
13	"	94·78	0·90	0·72	—	3·60
14	"	95·56	—	0·35	0·11	3·98

it will become apparent that in some instances there were indications of traces of a hydrocarbon other than marsh-gas. The quantity of this hydrocarbon, which I have every reason to think is hydride of ethyl, is, however, so small that I have not taken it into account; and in making up the analysis it has been calculated as marsh-gas. The blowers showing these traces of other gases were invariably examined for olefiant gas; but in no instance was its presence detected.

Some time after collecting and analysing sample 13, I revisited the colliery for the purpose of forming some idea of the illuminating power of the gas, and I connected an ordinary fish-tail gas burner by means of an indiarubber tube to a pipe which conveyed the mine-gas. A very appreciable amount of light was obtained. In the same manner a Silber patent Argand burner was tried; but in this experiment no illuminating power was shown by the mine-gas; the flame resembled th[illegible] Bunsen burner. The gas was next passed through [illegible]ining carded cotton, to remove any particles [illegible]hich may have been carried along; but although the flame was smaller, owing to the resistance offered by the cotton, it appeared to have an equal illuminating power. I may also mention that several cubic feet of the gas were passed through a solution of plumbic nitrate without giving any indication of sulphuretted hydrogen. The other blowers were also tested for this gas, but gave no evidence of its presence.

On examining the analyses of these blowers side by side with those from the North of England coal-fields already referred to, the high percentage of marsh-gas and comparatively low percentage of nitrogen strike one most forcibly. It is also curious to observe the great similarity between the blower gases which I have examined.

On comparing, for instance, gas No. 3, obtained from the top rock of the seam, with gas No. 4, obtained by boring into the body of the coal, the percentage composition appears almost identical, showing that the blower must have been fed from the same seam. The gases No. 3 and No. 4, together with coal No. 6 (Part I.), were procured not only from the same seam, but also within a few yards of each other. The gas No. 4 evolved by the *seam* of coal contained only ·44 per cent. of carbonic acid, while the gas obtained by exhausting the portion of coal No. 6 taken out of the same seam, gave 5·46 per cent. of carbonic acid. The portion of coal referred to was cut from the middle of a large lump; and as no air had previously been in contact with it, the carbonic acid in the enclosed gases must have been present in the coal before being cut from the seam. Now, since the gases enclosed in the steam-coals, which were left exposed to the atmosphere, escaped somewhat in accordance with the law of diffusion, some idea may be formed from the above comparisons of the enormous volume of gas which is held enclosed in the coals of this class prior to their removal from the seam or vein.

Before concluding, I desire to express my gratitude to Dr. Frankland for his ever-ready and valuable advice.

In acknowledging my obligations to the colliery proprietors, I must admit my inability to express my full sense of the courtesy which I received at their hands, as well as the truly kind services rendered by their managers and sub-officers.

ON THE GASES ENCLOSED IN CANNEL COALS AND JET.

(Reprinted from the 'Journal of the Chemical Society,' August 1876.)

THE analyses of the gases enclosed in anthracite, bituminous, and steam coals, were given in a former paper ('Chemical Society's Journal' [2], xiii. 793), and reference made to the work which had been previously done in this direction. The gases enclosed in cannel—another important class of coal used for the manufacture of coal gas, &c.—have not, as far as I am aware, been determined.

The method used for obtaining the enclosed gases was similar to that described in the paper referred to, with the exception that Florence flasks, having their necks drawn out and bent over, were substituted for glass tubes when Scotch cannel was employed, a large quantity of coal being required to furnish the necessary volume of gas. These coals were broken in a mortar and passed through a sieve having 9 meshes to the inch, and the dust was removed by a sieve having 64 meshes to the inch.

The following table shows from whence the cannel coals and jet were obtained.

Cannel coals are usually very hard and close-grained, fracturing conchoidal, without crumbling, and when placed in a vacuum do not evolve any appreciable quantity of gas. No. 1 was somewhat porous, and resembled, in appearance, the hardest steam coals of the South Wales basin.

No. of Sample	Description	District
1	Wigan cannel, $\frac{5}{3}$ seam, 350 yards deep	Wigan Arley Mine, Lancashire coal-field
2	Wigan cannel, $\frac{3}{2}$ seam, 600 yards deep	Lancashire coal-field
3	Scotch cannel (Heywood cannel, Wilsontown)	Lanark
4	Scotch Cannel (Lesmahagow)	—
5	Whitehill cannel shale, Lasswade	Edinburgh
6	Whitby jet (finest quality for ornaments)	Whitby

The following are the results I obtained :—

SAMPLE NO. 1.—*Wigan Cannel, from Wigan Arley Mine.*

100 grms. of coal evolved 421·3 c.c. of gas at 100° C. (212° F.).

The last portion of air exhausted in forming a vacuum contained 20·54 per cent. of oxygen.

Analysis of the gas evolved at 100° C. (212° F.) :—

	Composition in 100 parts.
Carbonic acid	6·44
Marsh-gas	80·69
Hydride of ethyl	4·75
Nitrogen	8·12
	100·00

SAMPLE NO. 2.—*Wigan Cannel.*

100 grms. of coal evolved 350·6 c.c. of gas at 100° C. (212° F.).

The last portion of air exhausted in forming a vacuum contained 20·77 per cent. of oxygen.

Analysis of the gas evolved at 100° C. (212° F.) :—

	Composition in 100 parts.
Carbonic acid	9·05
Marsh-gas	77·19
Hydride of ethyl	7·80
Nitrogen	5·96
	100·00

The tube containing the coal was heated for two days until apparently exhausted; the last portion of gas brought over was of the following composition.

Analysis of the last portion evolved at 100° C. (212° F.):—

	Composition in 100 parts.
Carbonic acid	3·97
Marsh-gas	79·58
Hydride of ethyl	15·32
Nitrogen	1·13
	100·00

The first portion of sample No. 2 gave off gas readily, about twice its volume being evolved in six hours. On the second day it was again heated for ten hours; some of the higher hydrocarbons of the paraffin series were condensed in the connecting-tube of the Sprengel, and also brought over by the pump. On the third morning a white crystalline substance was formed in the connecting-tube, which, together with the tubes in which the gas was collected, emitted the odour of the oils obtained from petroleum distilled at 100° C. (212° F.). I was unable to obtain satisfactory results, owing to the presence of so much oily matters brought over by the Sprengel pump.

A second portion of the coal was taken and connected with the Sprengel in the usual manner. The branch tube holding the water-joint was made of extra length, and of such a form as to admit of its being surrounded with freezing mixture. The gas brought over was thus obtained more free from vapour of the higher hydrocarbons.

This coal was again heated to 200° C. (392° F.) when a further quantity of gas was evolved equal to 276·2 c.c. per 100 grms. of coal. In spite of the cooling effect of the freezing mixture, some oily matters and vapour were brought over by the pump, and the results of the analyses were not sufficiently concordant to enable one to calculate the percentage of the hydrocarbons present. It was interesting, however to observe the deposition of oily matters in the neck of the flask in which the coal was placed, as well as along a considerable length of the connecting tube. This coal appears to hold in a condensed form the whole of the paraffins from quartane or ethyl upwards, together with the g[illegible]nic acid, nitrogen, marsh-gas, hydride of ethyl, and p[illegible] of propyl.

A portion of this coal was m[illegible] hours under a partial vacuum at 50° C. (122° F.), and the gas evolved smelt strongly like crude petroleum, and the surface of the water (from the coal) in the connecting-tube (which was immersed in freezing mixture) was covered with oily matter, which disappeared shortly after the apparatus was disconnected.

SAMPLE NO. 3.—*Scotch Cannel, Heywood Colliery, Wilsontown.*

100 grms. of coal evolved 16·8 c.c. at 100° C. (212° F.).

The last portion of air exhausted in forming a vacuum contained 20·86 per cent. of oxygen.

Analysis of the gas evolved at 100° C. (212° F.):—

	Composition in 100 parts.
Carbonic acid	53·94
Nitrogen	46·06
Traces of hydrocarbons	—
	100·00

SAMPLE NO. 4.—*Lesmahagow Cannel.*

100 grms. of coal evolved 55·7 c.c. of gas at 100° C. (212° F.).

The last portion of gas exhausted in forming a vacuum contained 20·99 per cent. of oxygen.

Analysis of the gas evolved at 100° C. (212° F.):—

	Composition in 100 parts.
Carbonic acid	84·55
Nitrogen	14·54
Gases and vapour of the paraffin series agreeing with hydride of propyl	0·91
	100·00

SAMPLE NO. 5.—*Cannel Shale, Lasswade, Edinburgh.*

100 grms. of the shale evolved 15·7 c.c. of gas.

The last portion of air exhausted in forming a vacuum contained 20·85 per cent. of oxygen.

Analysis of the gas evolved at 100° C. (212° F.):—

The absence of oxygen was proved by previous analyses.

	Composition in 100 parts.
Carbonic acid	68·75
Gases of the paraffin series agreeing with hydride of ethyl and hydride of propyl	2·67
Nitrogen	28·58
	100·00

SAMPLE NO. 6.—***Whitby Jet (finest quality).***

100 grms. of jet evolved 30·2 c.c. of gas at 100° C. (212° F.).
Analysis of the gas evolved at 100° C. (212° F.) :—

	Composition in 100 parts.
Carbonic acid	10·93
Quartane or ethyl	86·90
Nitrogen	2·17
	100·00

The contraction of volume after explosion, carbonic acid absorbed, and oxygen consumed when compared with the volume (sample 6), correspond nearly with quartane or ethyl, including probably a little vapour of other hydrocarbons higher in the series. Absolute alcohol absorbs more than three-fourths of the entire volume of gas withdrawn from jet, and gives it up again on the addition of water.

The following table gives the quantity of gases evolved as well as their composition :—

COMPOSITION OF GASES.

No. of Sample	Gas evolved by 100 grms. of coal at 100° C. (212° F.) under a vacuum	Carbonic acid	Marsh-gas	Hydride of ethyl	Quartane, or ethyl	Nitrogen
	c.c.					
1	421·3	6·44	80·69	4·75	—	8·12
2	350·6	9·05	77·19	7·80	—	5·96
3	16·8	53·94	—	—	—	46·06
4	55·7	84·55	—	—	$\left\{ \begin{matrix} C_3H_8 \\ 0·91 \end{matrix} \right\}$[1]	14·54
5	15·7	68·75	—	2·67	—	28·58
6	30·2	10·93	--	—	86·90	2·17

The coals examined by Meyer from the Newcastle and Durham coal fields[2] did not contain any hydrocarbon other than marsh-gas.

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[1] Hydride of propyl.

[2] Abstract of paper published in the *Journal für praktische Chemie* [2], v. 144–183; 407–427; and vi. 389–416 will be found in the *Chem. Soc. Journal* [2], x. 798 and 801; and xi. 483.

The bituminous, anthracite, and steam coals, already referred to at the commencement of this paper, also contained only carbonic acid, marsh-gas, oxygen and nitrogen as occluded gas.

It will be seen, however, that the cannel coals differ considerably from those mentioned, inasmuch as they enclose hydride of ethyl, and most probably hydride of propyl and all the paraffin series. I am unable to determine the presence or absence of hydride of propyl in a mixture containing marsh-gas and hydride of ethyl, as two volumes of hydride of propyl and two volumes of marsh-gas are equal to four volumes of hydride of ethyl. I have, therefore, calculated the volume of explosive gas as marsh-gas and hydride of ethyl.

The whole of the cannel coals and jet contain the gases of the paraffin series and oily matters, which appear to belong to the same. Wigan cannels, with regard to the gases which they hold enclosed, occupy a position intermediate between steam coal and Scotch cannel; and Scotch cannel occupies a position intermediate between bituminous (house) coals and Wigan cannel. Thus, in the Wigan cannels, there is a large volume of gas, consisting for the most part of marsh-gas, with a low percentage of carbonic acid and nitrogen, and, *in these respects*, closely allied to the steam coals. The Scotch cannels, on the other hand, contain but little gas, which consists almost entirely of carbonic acid and nitrogen, similar to the bituminous class of house coals. Scotch cannel contains a small quantity of the higher hydrocarbon gases. Owing to the high percentage of carbonic acid present, it became possible to employ a large and concentrated volume for the determination of the combustible gases.

In the analysis of sample 4, the respective volumes of the contraction after explosion, carbonic acid formed, and oxygen consumed, when compared with the volume, agree nearly with hydride of propyl; it is possible, therefore, that marsh-gas, hydride of ethyl, quartane or ethyl, may be present also.

In sample No. 5, hydride of ethyl and hydride of propyl agree nearly with the respective volumes above mentioned.

The gases from all the cannel coals have been treated with fuming sulphuric acid and ammonio-cuprous chloride. Some of them showed indications of gases belonging to the olefiant series, but it is probable that the loss in volume was due to the absorption of the vapour of the higher hydrocarbons, because, when the whole volume of combustible gas was exploded, the carbonic acid formed, oxygen consumed, and contraction due to explosion, did not agree with the calculated volume.

Negative results were obtained with ammonio-cuprous chloride, showing the absence of carbonic oxide.

Absolute alcohol absorbed more or less gas in all instances, but the total volume of combustible gas was insufficient to obtain decided results with the Scotch cannels. The gases obtained from sample No. 5, after absorption with absolute alcohol, and exploding with oxygen by the aid of hydrogen, yielded only 1 per cent. of combustible gas, and the hydride of ethyl in cannel No. 2 was considerably lessened after absorption with alcohol.

Jet differs from the harder cannel by occluding only a small percentage of carbonic acid and nitrogen, and also by containing a large percentage of quartane or ethyl gas. The tube in which the gases were brought over by the pump contained one or two tenths of a c.c. of oily matter emitting the odour of paraffin. It is necessary when working with any coal, or carbonaceous material whatever, for the purpose of obtaining its enclosed gases, to first ascertain by experiment the volume which is evolved at the required temperature. In this manner, a portion of the substance can be taken which shall yield the quantity of gas necessary for analysis, and shall not be too large to be collected in one tube; and the coal should be exhausted before using any of the gas for analysis, unless it be required to ascertain the deportment of the gases under a vacuum.

In conclusion, I would express my thanks to those gentlemen who favoured me with the coals and jet.

ON THE GASES ENCLOSED IN LIGNITE AND MINERAL RESIN FROM BOVEY HEATHFIELD, DEVONSHIRE.

(*Reprinted from the 'Journal of the Chemical Society,' August*, 1877.)

THE gases present in an occluded form in the lignites of Bovey Heathfield have not, as far as I am aware, been determined, and the analyses herein noted are a continuation of the researches which I have previously had the honour of communicating to this society, 'On the gases enclosed in various coals.'[1]

The method which I employed to obtain the gases was similar to that described in a former paper,[2] using for the coal vessel either a long tube or a Florence flask, the neck of which was hermetically joined to a bent tube for connection with the Sprengel pump.

The coals (Nos. 2 and 3) from which the gases were extracted were the best specimens now procured for fuel purposes. They were in a very moist condition, containing, as they did, from 36 to 44 per cent. of water; and in order to procure all the gases which they occlude, it is obviously necessary to use them in their wet condition.

The gases enclosed in some lignites from Bohemia were examined by Zitowitsch,[3] who found them to consist of carbonic acid, oxygen, carbonic oxide, and nitrogen.

The following is a description of the coals employed :—

No. 1, lignite, consisted of the leaves and stems of plants in a closely compressed condition, and is known locally as 'leafy' coal.

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[1] *Chem. Soc. Journal* [2], xiii. 793; and vol. xxx. 144.

[2] *Ibid* [2], xiii. 794.

[3] *J. Pr. Chem.* [2], vi. 79.

No. 2 lignite, was dense and compact, of a distinctly woody character, and fractured with the grain—colour, dark brown.

No. 3, lignite, was very dense, but earthy and wet in appearance, and, to the unaided eye, structureless: the cleavage and fractures parallel with the bed much incrusted with hydrated oxide of iron—colour, nearly black.

No. 4, mineral resin, is that named 'Retinasphaltum,' by Hatchett.[1] It is a brown, soft, powdery substance, lighter than water. All the coals yield an extract with alcohol similar to that afforded by the 'resin.'

A portion of No. 2 was placed in a tube and connected with the Sprengel in the usual manner. This coal contained a large proportion of water, and, in consequence, much of the latter became condensed in the connecting tube of the Sprengel, and was subsequently carried over by the pump into the tube used for collecting the gases. After two days' exhaustion at 100° C. (212° F.), there was only a small quantity of gas brought over, and apparently three times as much water. The gas was analysed and its composition found to be in 100 parts :—

Carbonic acid	76·12
Oxygen	0·34
Carbonic oxide	1·40
Nitrogen	22·14
	100·00

In the process of analysis, the contents of the collecting tube (gas 3·2 c.c. and water over mercury) were introduced into the laboratory tube of the gas apparatus, and the gas transferred to the eudiometer; and as it was found that the water remaining in the laboratory tube continued to evolve gas, the laboratory tube and its contents were removed to another mercury trough, and the analysis of the gas above given completed with a second one. Afterwards the laboratory tube containing the water referred to was connected with the apparatus, and the water drawn over into the eudiometer, and subjected to the expanding influence of 40 inches of mercury. A further quantity of gas was given off rapidly, and 2·9 c.c. was thus obtained, which gave, on analysis, 99·83 per cent. of carbonic acid.

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[1] *Phil. Trans.*, 1804, part i. 396.

It will be seen, therefore, that the method of obtaining and collecting gases in tubes containing water is far from being reliable, especially when much carbonic acid is present, and the collection of gas in the experiment referred to was similar in effect to the process employed by Dr. Meyer,[1] and afterwards used by Zitowitsch, because by boiling coal with de-aërated water, much of the latter would be distilled over, and it would not be possible to collect the gases apart from it. It is probable, therefore, that the percentage of carbonic acid is much too low in the results of the two lignites from Bohemia examined by Zitowitsch.

I recently determined the enclosed gas (withdrawn at 100° C. (212° F.) in a sample of Bohemian lignite from Prenzig, near Komatau, with the following result:—

	Composition in 100 parts.
Carbonic acid	96·41
Oxygen	0·32
Carbonic oxide	1·20
$C_n H_{2n}$ (olefiant gas, &c.)	traces
Nitrogen	2·07
	100·00

The percentage of carbonic acid found by Zitowitsch in the two lignites examined was 89·66 and 83·99 respectively.

Having inferred from the analysis before given of the gas obtained from No. 2, that no gas was present which would interfere with the use of strong sulphuric acid to absorb the water from the coal, I introduced a flask containing this acid between the connections of the tube containing the coal and the Sprengel pump. The gas and water evolved from the coal in a vacuum must pass through the sulphuric acid and all the water would consequently become absorbed.

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[1] *Chem. Soc. Journal* [2], x. 798.

No. 2 coal was first employed, and a much larger quantity of gas was obtained than in the previous experiment without acid for dehydrating, but I could not succeed in obtaining concordant results, and, although each coal was in turn taken, and treated in the same manner, no trustworthy results could be worked out. The absorption by potash and pyrogallic acid gave very variable results, and no two analyses of the combustible portion of the gas came out alike. On account of the difficulties experienced, I undertook the experiments on gas-absorptions, the results of which were recently communicated to this Society. Nitric oxide was found to be present in the gaseous mixture, and the diminution of volume by treating with pyrogallic acid, after absorbing carbonic acid by potash, was due to the absorption of nitric oxide. The nitric oxide came from the sulphuric acid employed, and I have found from experiments that when the acid becomes diluted by the absorption of water in a vacuum, this gas is evolved in some quantity. I mention this more particularly, in case sulphuric acid may be employed for a like purpose, and because it is often used for dehydrating compounds in a vacuum; and in some instances, probably the nitric oxide, which is evolved when the acid becomes diluted, may act upon or yield oxygen to the compound which is in process of dehydration.

After having made a number of experiments, which at first promised to give good results, they were found to be unreliable, and are not recorded in consequence. Still retaining the globular flask in which the sulphuric acid was placed, but without any acid in it, I immersed the same in a vessel containing freezing mixture, and commenced with a portio [illegible] 1 coal, keeping the temperature at 50° C. (1 [illegible] he first period of the experiment, in order to ascertain if any decomposition set in at 100° C. (212° F.). It is surprising how small a quantity of water was brought over by the Sprengel, and that too when the temperature of the water cooled by the freezing mixture (ice and salt) approached that of the ordinary temperature 15° C. (27° F.) of the laboratory. This appeared to be owing to the large internal surface of the flask, the water given off by the coal condensing on the sides, and it was found possible, by regulating the action of the Sprengel, to bring over the gas evolved at 50° C. (122° F.) almost entirely free from water without the aid of any freezing mixture. When the temperature of the lignite was raised to 100° C. (212° F.), there was a tendency for more water to pass into the collecting tube; but by allowing the pressure of the gas (evolved in a partial vacuum) to reach about half the normal (15 inches of mercury) before working the Sprengel, sufficient gas for an analysis could be procured practically free from water. The following are the results obtained:—

No. 1.—*Leafy Coal (Lignite) from Bovey Heathfield.*

100 grams of coal evolved 56·1 c.c. of gas at 50° C. (122° F.) after prolonged heating for twelve days and nights. During the first two days more than 90 per cent. of the gas obtained was given off, and after the fourth day the coal appeared to be practically exhausted at 50° C. (122° F.).

The last portion of air and gas exhausted in forming a vacuum at the ordinary temperature (13° C., 55° F.) gave on analysis:—

Carbonic acid	2·40
Oxygen	18·66
Nitrogen	78·94
	100·00

Analysis of the gas evolved at 50° C. (122° F.):—

	Composition in 100 parts.
Carbonic acid	87·25
Oxygen	0·24
Carbonic oxide	3·59
Nitrogen	8·92
	100·00

No. 1, lignite, after heating at 50° C. (122° F.), was kept at 100° C. (212° F.) for 18 days and nights, the loss of water (in a beaker kept boiling around coal) by evaporation being renewed by a self-acting contrivance similar to Bischof's apparatus for water analysis. The gas came over rapidly for the first hour, but only traces were afterwards obtained.

100 grams of coal evolved 59·9 c.c. of gas at 100° C. (212° F.).

A rather considerable portion of water and oily matters having a somewhat agreeable aromatic odour was brought over by the Sprengel, owing to the length of time which the coal was maintained at 100° C. (212° F.) The composition of the gas, after correction for the amount of gas extracted from the water in the collecting tube, by placing it under diminished pressure, was found to be:—

Carbonic acid	89·53
C_nH_{2n} (Olefiant gas, &c.)	0·33
Carbonic oxide	5·11
Nitrogen	5·03
	100·00

The beaker containing boiling water in which the tube holding the coal was immersed was removed, and a paraffin bath substituted for it. The temperature was then raised and maintained at 200° C. (392° F.) At about 150° C. (302° F.) decomposition set in, and the surface of the mercury in the collecting tube, as also the pellets of the metal as they fell down the Sprengel capillary tube, became blackened by the formation of sulphide of mercury. The contents of the first tube collected emitted a very powerful but somewhat agreeable aromatic odour, while the sulphide of mercury adhered in scaly films to the inside of the collecting tube. The second tube of gas brought over presented the same appearance as the first as regards the deposit of sulphide, but a most disagreeable odour masked the presence of the aromatic compounds. The third tube was coated with sulphide of mercury, but emitted a still more disagreeable odour than the second—the odour of organo-sulphur compounds, among which mercaptan appeared to be present. After the gas was transferred to the apparatus for analysis, the odour of the more volatile sulphur-compounds gradually disappeared, leaving an unmistakable evidence of the presence of sulphide of allyl. Some of the latter com [illegible] de from garlic, for the purpose of comparison

During the time the analysis and collection of the gas evolved at 200° C. (392° F.) was proceeding, my laboratory was for days scented with the fragrance of garlic and onions. Great difficulty was experienced in removing the oily and empyreumatic vapours from the Sprengel and connecting tubes, as well as from the eudiometer of the gas apparatus. The gas retained the vapour of allyl-sulphide, after absorbing the gases of the olefiant series by fuming sulphuric acid. The quantity of gas evolved at 200° C. (392° F). during the first hour was very considerable, but soon became very much less.

Composition of first 18 c.c. evolved at 200° C. (392° F.):—

	Composition in 100 parts.
Carbonic acid	88·39[1]
$C_n H_{2n}$ (Olefiant gas, &c.)	2·32
Carbonic oxide	8·83
Nitrogen, and undetermined gas	0·46
	100.00

A second analysis of the first portion of gas collected showed by indirect estimation that the gas absorbed by fuming sulphuric acid was one of low carbon atoms, probably olefiant gas. The second tube of gas evolved at 200° C. (392° F.) was analysed with the following result:—

	Composition in 100 parts.
Carbonic acid	82·06
Sulphuretted hydrogen	2·82
Carbonic oxide	14·00
Marsh-gas	0·49
Propylene	0·48
Nitrogen	0·15
	100·00

In the above analysis the calculating volumes are of course too close to theory to be correct, as there is doubtless some vapour of the sulphur-compounds, and oily matters present as well.

An analysis of the last gas collected at 200° C. (392° F.) showed that the percentage of carbonic acid was gradually decreasing, while the carbonic oxide increased. The same portion of coal No. 1 was heated up to 250° C. (482° F.) with the intention of raising the temperature to 300° C. (572° F.), but this was prevented, owing to the action of the sulphur-compounds upon the mercury being so energetic that the capillary tube of the Sprengel became blocked up. Acid vapours of similar odour to those evolved during the carbonisation of wood in iron retorts, were given off toward the end of the experiment. A portion of gas collected at 250° C. (482° F.) was analysed, with the following results:—

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[1] There is a small percentage of sulphuretted hydrogen included in the carbonic acid left undetermined by mistake.

	Composition in 100 parts.
Sulphuretted hydrogen	5·85
Carbonic acid	71·13
$C_n H_{2n}$ (Olefiant gas, &c.)	1·09
Carbonic oxide	16·20
Marsh-gas	5·46
Nitrogen	0·27
	100·00

No. 2.—*Lignite (woody) from Bovey Heathfield.*

100 grams of lignite evolved 48·5 c.c. of gas at 50° C. (122° F.). An analysis of the last portion of air exhausted in forming a vacuum gave in 100 parts:—

Carbonic acid	4·52
Oxygen	14·52
Carbonic oxide	traces
Nitrogen	80·96
	100·00

This portion of air and gas measured 15·1 c.c. A small portion of air collected previous to this gave 20·79 per cent. of oxygen. The quantity of coal employed in this experiment was very large, viz. 140·3 grams. It is a remarkable fact that nitrogen escapes from coal more rapidly than apparently any other gas. This circumstance may be noticed in the analyses of the enclosed gases given in the previous papers. The gas evolved at 50° C. (122° F.) was collected in five separate tubes, and the gaseous contents of each were subjected to analysis.

Analyses of the gas evolved at 50° C. (122° F.) :—

	1st portion.	2nd portion.	3rd portion.	4th portion.	5th portion.
Carbonic acid . . .	79·12	96·62	97·29	96·10	96·23
Oxygen	0·51	0·33	0·21	0·19	0·11
Carbonic oxide . .	4·14	lost	1·40	2·93	2·42
$C_n H_{2n}$ (Olefiant gas, &c.)	trace	„	trace	trace	trace
Nitrogen	16·23	„	1·10	0·78	1·24
	100·00	—	100·00	100·00	100·00

The average percentage of carbonic acid, after allowing for the difference in volume of the gas in five tubes, was about 94 per cent. Some oily matters, having a pleasant aromatic odour, were brought over by the pump. These aromatic compounds must have low boiling points, as they are evolved at 15° C. (27° F.) in a vacuum.

After remaining night and day in a vacuum at 50° C. (122° F.) for eight days (No. 2, woody), the temperature was raised to 100° C. (212° F.) and maintained for 14 days and nights.

100 grammes of lignite evolved 114·3 c.c. of gas at 100° C. (212° F.).

Analysis of the gas evolved at 100° C. (212° F.), 1st portion :—

	Composition in 100 parts.
Carbonic acid	96·74
Carbonic oxide	2·80
Nitrogen, and other undetermined gas . .	0·46
	100·00

The second, third, and fourth portions of gas evolved at 100° C. (212° F.) were mixed, and the carbonic acid determined in a small part, and found to be 96·05 per cent. The carbonic acid was then absorbed from the whole of the gas, and the residue used for determining the carbon gases. The composition in 100 parts was :—

Carbonic acid	96·05
Carbonic oxide	3·20
$C_n H_{2n}$ (Olefiant gas, &c.)	0·33
Nitrogen	0·42
	100·00

The contents of five other tubes were treated in a similar manner, the composition of the mixed gas in 100 parts being:—

Carbonic acid	95·34
Carbonic oxide	3·83
$C_n H_{2n}$ (Olefiant gas, &c.)	0·61
Nitrogen	0·22
	100·00

The calculated volumes of the combustible gas showed the presence of traces of higher hydrocarbons.

Had the coal remained longer in a vacuum at 100° C. (212° F.), a little more gas would be evolved, but the quantity was gradually growing less and less. Small yellow crystals of sulphur, which I mistook at first for succinic acid, were formed by sublimation from the coal, on the inside of the tube, just above the level of the boiling water in which the tube was immersed, and this happened in every instance in which this lignite (No. 2, woody) was employed, but not so with the other lignites.

A fresh portion of No. 2 lignite was heated up to 200° C. (392° F.), after previous heating for some time at 100° C. (212° F.). When the temperature rose to 180° C. (356° F.), there was no apparent change, the pump bringing over only traces of gas. At 185° C. (365° F.) destructive distillation commenced. The tube in which the gas evolved at 200° C. (392° F.) was collected emitted the odour of sulphide of allyl, but only traces of sulphuretted hydrogen were present in the gas collected, as there was much moisture in the Sprengel connections.

The quantity of sulphur compounds evolved by No. 2 lignite at 100° C. (212° F.) was not so great as that given off by the other coals.

The aromatic odour of the oily matters, which belong probably to the terpenes, was distinguishable, although masked in a great degree by the allyl sulphide.

Analysis of the gas evolved at 200° C. (392° F.) :—

	Composition in 100 parts.
Carbonic acid	86·30
Carbonic oxide	7·41
Gases of the olefiant series	2·08
Marsh-gas	3·34
Hydride of propyl	0·53
Nitrogen	0·34
	100·00

The above figures were obtained from closely agreeing analyses. The calculating volumes indicated that hydride of propyl was present, and the result was made out accordingly. It is possible, however, that the vapour of liquid compounds may take part in the explosion, although the greater portion would be broken up by the fuming sulphuric acid used for absorbing the olefiant gases, &c.

No. 3.—*Lignite, from Bovey Heathfield.*

This coal was heated in a vacuum at 50° C. (122° F.) for 4 days and 5 nights, when gas was evolved equal to 68·1 c.c. per 100 grams of lignite. The last portion of air and gas exhausted in forming a vacuum at the ordinary temperature gave in 100 parts :—

Carbonic acid	2·42
Oxygen	17·26
Nitrogen	80·32
	100·00

The gas evolved at 50° C. (122° F.) was collected in three tubes.

Analysis of the gas collected at 50° C. (122° F.), 2nd tube :—

	Composition in 100 parts.
Carbonic acid	98·30
Carbonic oxide	1·35
Hydrocarbon gas	trace
Nitrogen and trace of oxygen	0·35
	100·00

The gas in first and third tubes was analysed, with the following result :—

	Composition of gas in 1st tube.	3rd tube.
Carbonic acid	94·12	98·27
Oxygen	·28	—
Carbonic oxide	2·13	1·15
$C_n H_{2n}$ (Olefiant gas, &c.)	trace	0·19
Nitrogen	3·47	0·39
	100·00	100·00

The average percentage of carbonic acid was 96·83.

The same portion of coal (No. 3) was next heated to 100° C. (212° F.), during two and a half days and two nights, when gas was evolved equal to 86·3 c.c. per 100 grams of lignite. The following is the composition of the gas evolved at 100° C. (212° F.), 66 c.c. being used for the determination of the combustible gas.

	Composition in 100 parts.
Carbonic acid	97·77
Carbonic oxide	1·69
$C_n H_{2n}$ (Olefiant gas, &c.)	0·21
Nitrogen	0·33
	100·00

The same portion of coal (No. 3) was next heated to 200° C. (392° F.), when a considerable quantity of gas was evolved, active decomposition having commenced about 180° C. (356° F.).

Analysis of the gas evolved at 200° C. (392° F.) :—

	Composition in 100 parts.
Sulphuretted hydrogen	0·41
Carbonic acid	91·68
$C_n H_{2n}$ (Olefiant gas, &c.)	0·41
Carbonic oxide	7·12
Hydrogen	traces
Nitrogen	0·38
	100·00

No. 4.—*Mineral Resin, from Bovey Heathfield.*

This substance was heated at 50° C. (122° F.), but did not yield sufficient gas for analysis. The temperature was raised to 100° C. (212° F.), when gas was evolved equal to 21·4 c.c. per 100 grammes of 'resin.'

The last portion of air and gas exhausted in forming a vacuum at the ordinary temperature (15° C., 27° F.) gave on analysis :—

Carbonic acid	2·65
Oxygen	17·94
Nitrogen	79·41
	100·00

Analysis of the gas evolved in a vacuum at 100° C. (212° F.) :—

	Composition in 100 parts.
Carbonic acid	88·24
Oxygen	0·23
$C_n H_{2n}$ (Olefiant gas, &c.)	0·47
Carbonic oxide	7·90
Nitrogen	3·16
	100·00

The tube containing the mineral resin was further heated in a paraffin bath, with the intention of raising the temperature to 200° C. (392° F.). Between 110° C. (230° F.) and 120° C. (248° F.) the 'resin' began to melt, and decomposition set in at once. Much sulphur compounds were evolved, which attacked the mercury in the pump to such an extent that before the 'resin' was heated above 160° C. (320° F.), it became impossible to bring the gas over. Previous to this, however, a quantity of gas was obtained equal to 180 c.c. per 100 grams of substance. The odour of the vapour present in the tube in which the gas was collected was not unlike that of the so-called oil of amber; no sulphide of allyl was present. The composition of the gas obtained at 150° C. (302° F.), calculated from closely agreeing figures, was :—

	In 100 parts.
Sulphuretted hydrogen	0·41
Carbonic acid	78·88
$C_n H_{2n}$ (Olefiant gas, &c.)	2·67
Carbonic oxide	7·82
Marsh-gas	8·05
Hydride of propyl	1·86
Nitrogen	0·31
	100·00

When the Bovey Heathfield lignites are compared with the coals of the carboniferous period, there exists as much difference with regard to their occluded gas as there is to their structure and general character. The chemical composition of the lignites approaches that of some of the cannel and bituminous coals, but their structure is very dissimilar. So far as the occluded gas is concerned, these lignites approach nearer to the cannel coals than any other, but there are material differences between them. The greater portion of the gas enclosed in cannel coal and lignite consists of carbonic acid; but while the former contains the gases, and apparently the compounds of the paraffin series, the latter contain olefiant gas, &c., and oily matters of the aromatic series, in addition to appreciable quantities of carbonic oxide.

The lignites are far less stable bodies than the coals of the carboniferous formation, as they undergo decomposition in a vacuum at a much lower temperature—all those examined, below 200° C. (392° F.). The coals of the carboniferous period remain unaltered at that temperature, and usually resist decomposition at 300° C. (572° F.).

It is possible that slow oxidation, proceeding at the expense of the combined oxygen, may take place in a vacuum at 100° C. (212° F.); but, as will be seen from the analyses, there is no difference in the nature of the gases evolved either at 50° C. (122° F.) or 100° C. (212° F.). The apparent traces of olefiant gas and other gases which are calculated and recorded in percentage, in some of the analyses, would lead one, at first sight, to ridicule the idea of attempting such calculation; but by absorbing the carbonic acid from a *large* volume of gas, 50 c.c. for instance, a very appreciable residue could be obtained for the purpose of determining olefiant gas, carbonic oxide, &c.

With regard to the sulphur compounds and to the state of combination in which the sulphur exists in the lignites, very little absolute information has been obtained. The crystals of sublimed sulphur deposited from No. 2 at the temperature of 100° C. (212° F.) in a vacuum, seem to show that some sulphur compound is present, which is capable of being decomposed with facility, or that free sulphur exists in the lignite. When there was little water in the Sprengel connections, a considerable quantity of sulphuretted hydrogen was mixed with the ga [illegible] t the reverse was the case when m [illegible] Owing to the fact that the figures of the analyses did not show the presence of free hydrogen (excepting the one instance where there appeared to be a trace), it is very probable that the sulphur of the mercury sulphide formed in the Sprengel and collecting tube was derived from the breaking up of some sulphur compound other than sulphuretted hydrogen. When the gas was imprisoned between the pellets of mercury (as the Sprengel was in the act of bringing over the gas), an energetic action appeared to be going on, as shown by the very appreciable quality of sulphide of mercury formed. It is probable, therefore, that the nature of some of the sulphur compounds, evolved in a vacuum by the coal, were altered or broken up before reaching the collecting tube, the more stable, especially sulphide of allyl, alone escaping decomposition. The presence of sulphur in organic combination in No. 1 and No. 3, which contain, in their fresh condition, hydrated oxide of iron between the natural cleavages of the coal, as also in some parts throughout their mass, indicates that the process of conversion of these substances into true coal has not advanced sufficiently to convert the organo-sulphur compounds into sulphide of iron. The films of oxide of iron referred to, which are deposited probably by the reducing action of the coal upon iron salts dissolved in the water which sinks into the coal strata, suggest that the layers of iron pyrites and crystalline nodules of the same may have derived their sulphur from that which originally existed in organic combination in the plants from which coal is produced. This view is more in harmony with the fact of organo-sulphur compounds being present in the coal, while hydrated oxide of iron is deposited in its mass, because it is evident that if we regard the iron pyrites of coal as the product of the reduction of sulphates by organic matter, the sulphur so liberated would enter into combination with the iron oxide in preference to forming organo-sulphur compounds. In those instances in which sulphur has been found in coal in the state of organic combination, its detection has resulted from the finding of more sulphur than corresponded with the amount of iron in the ash of the coal.

Had a portion of coal No. 1 or No. 3 been subjected to analysis, the sulphur it contains would not be regarded as being in organic combination, owing to the ample quantity of ash present. The sulphur and ash in these coals, calculated on the dry sample, were determined with the following result:—

	No. 1.	No. 3.
Sulphur	1·53	1·71
Ash	36·07[1]	17·98

The hygroscopic character of lignite has been pointed out by several observers. The Bovey lignites are especially hygroscopic; and so great is the affinity of these substances for water, that they will re-absorb from 10 to 12 per cent. in the space of a few hours after being thoroughly dessicated. All the water is not driven off from the lignites which I examined at 50° C. (122° F.), even in a vacuum, and after the coal has been completely dessicated at 100° C. (212° F.) in a vacuum, and the temperature allowed to fall to 30° C. (80° F.), the aqueous vapour which pervades the vacuous space is absorbed by the dry lignite so rapidly that the condensed water in the Sprengel tubes and connections flashes into vapour to supply its place, until in a short time the whole of the water is re-absorbed, provided it does not exceed 10 per cent. of the coal by weight.

In conclusion, I would express my grateful thanks to Wentworth Buller, Esq., for his kindness in supplying the samples of lignite and mineral resin.

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[1] Containing silica, 25·11.

ARISON OF FRENCH AND ENGLISH MEASURES. BY DR. WARREN DE LA RUE.

MEASURES OF LENGTH.

	In English Inches	In English Feet = 12 Inches	In English Yards = 3 Feet	In English Fathoms = 6 Feet	In English Miles = 1,760 Yards
Millimeter	0·03937	0·0032809	0·0010936	0·0005468	0·0000006
Centimeter	0·39371	0·0328090	0·0109363	0·0054682	0·0000062
Decimeter	3·93708	0·3280899	0·1093633	0·0546816	0·0000621
Meter	39·37079	3·2808992	1·0936331	0·5468165	0·0006214
Decameter	393·70790	32·8089920	10·9363310	5·4681655	0·0062138
Hectometer	3937·07900	328·0899200	109·3633100	54·6816550	0·0621382
Kilometer	39370·79000	3280·8992000	1093·6331000	546·8165500	0·6213824
Myriameter	393707·90000	32808·9920000	10936·3310000	5468·1655000	6·2138244

1 Inch = 2·539954 Centimeters.
1 Foot = 3·0479449 Decimeters.

1 Yard = 0·91438348 Meter.
1 Mile = 1·6093149 Kilometer.

MEASURES OF SURFACE.

	In English Square Feet	In English Sq. Yards = 9 Square Feet	In English Poles = 272·25 Sq. Feet	In English Roods = 10,890 Sq. Feet	In English Acres = 43,560 Sq. Feet
Centiare or square meter .	10·7642993	1·1960333	0·0395383	0·000988457	0·0002471143
Are or 100 square meters .	1076·4299342	119·6033260	3·9538290	0·098845724	0·0247114310
Hectare or 10,000 sq. meters	107642·9934183	11960·3326020	395·3828959	9·884572398	2·4711430996

1 Square Inch = 6·4513669 Square Cent meters.
1 Square Foot = 9·2899683 Square Decimeters.

1 Square Yard = 0·83609715 Square Meter or Centiare.
1 Acre = 0·404671021 Hectare.

MEASURES OF CAPACITY.

	In Cubic Inches	In Cubic Feet = 1,728 Cubic Inches	In Pints = 34·65923 Cubic Inches	In Gallons = 8 Pints = 277·27384 Cubic Inches	In Bushels = 8 Gallons = 2218·19075 Cubic Inches
Millilitre, or Cubic Centimeter .	0·061027	0·0000353	0·001761	0·00022010	0·000027512
entilitre, or 10 Cubic Centimeters	0·610271	0·0003532	0·017608	0·00220097	0·000275121
ecilitre, or 100 Cubic Centimeters	6·102705	0·0035317	0·176077	0·02200967	0·002751208
re, or Cubic Decimeter . .	61·027052	0·0353166	1·760773	0·22009668	0·027512085
litre, or Centistere . .	610·270515	0·3531658	17·607734	2·20096677	0·275120846
litre, or Decistere . .	6102·705152	3·5316581	176·077341	22·00966767	2·751208459
re, or Stere or Cubic Meter	61027·051519	35·3165807	1760·773414	220·09667675	27·512084594
ltre, or Decastere . .	610270·515194	353·1658074	17607·734140	2200·96676750	275·120845937

ubic Inch = 16·3861759 Cubic Centimeters. 1 Cubic Foot = 28·3153119 Cubic Decimeters. 1 Gallon = 4·543457969 Litres.

MEASURES OF WEIGHT.

	In English Grains	In Troy Ounces = 480 Grains	In Avoirdupois lbs. = 7,000 Grains	In Cwts. = 112 lbs. = 784,000 Grains	Tons = 20 Cwts. = 15,680,000 Grains
Milligram	0·015432	0·000032	0·0000022	0·00000002	0·000000001
Centigram	0·154323	0·000322	0·0000220	0·00000020	0·000000010
Decigram	1·543235	0·003215	0·0002205	0·00000197	0·000000098
Gram	15·432349	0·032151	0·0022046	0·00001968	0·000000984
Decagram	154·323488	0·321507	0·0220462	0·00019684	0·000009842
Hectogram	1543·234880	3·215073	0·2204621	0·00196841	0·000098421
Kilogram	15432·348800	32·150727	2·2046213	0·01968412	0·000984206
Myriagram	154323·488000	321·507267	22·0462126	0·19684118	0·009842059

1 Grain = 0·064798950 Gram. 1 Troy oz. = 31·103496 Gram. 1 lb. Avd. = 0·45359265 Killogr. 1 Cwt. = 50·80237689 Kilog.

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